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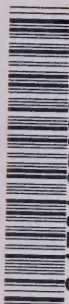
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EFFECTS OF SILTATION ON THE ECOLOGY OF YA-YA LAKE, NWT.
1980.

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Effects of Siltation on the Ecology of Ya-Ya Lake, N.W.T.

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Effects of Siltation on the Ecology of Ya-Ya Lake, N.W.T.

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INTRODUCTION

INTRODUCTION

Siltation is perhaps the single most common environmental disturbance to aquatic habitats associated with northern development activities. Investigations into the effects of sedimentation on aquatic biota in northern Canada have been conducted by Brunskill et al. (1973), Rosenberg and Snow (1975), Rosenberg and Wiens (1978), and McCart and de Graaf (1974). However, most of these studies were concerned with organisms in running water and, with the exception of a small scale experimental study of ponds in the vicinity of Stanwell-Fletcher Lake, N.W.T. (de March et al., 1977), no comparable investigations have been performed on lake ecosystems in the north.

This is a lack that should be remedied. First, lakes lack the inherent self-cleaning ability of streams and, for this reason, are probably even more sensitive to the adverse environmental effects of sedimentation than the latter. Second, lakes are very likely to be deliberately involved in the planning and construction of development projects. This involvement may be direct, as the location of float plane bases, winter landing strips, campsites and other support facilities, as water sources, or as disposal sites for sewage and other materials or indirect, where developments such as the Ya-Ya Lake borrow operations impinge on shorelines. Third, lakes are commonly important to local economies. They may be sources of water and fish for domestic use and habitat for

furbearing mammals and migratory waterfowl. In some instances, they have a high potential for the development of a tourist industry. All of these uses can be adversely affected by uncontrolled sedimentation.

Because only limited information is available describing the effects of sedimentation on northern lakes, there is no basis for establishing quantitative criteria to regulate sediment production associated with developments in the vicinity of lakes. In view of the potential for greatly increased petroleum-related and mining activities in the north, there is an obvious need for the development of such criteria.

Ya-Ya Lake on Richards Island in the Mackenzie Delta, N.W.T., was chosen as a site for field studies of the effects of suspended sediment loading on lake ecosystems. The lake is a multibasin system. Some basins within the system are affected by siltation, primarily by inflow from the Mackenzie River, while others remain undisturbed. It was hoped, therefore, that the lake would serve as a natural laboratory consisting of "disturbed" and "control" study areas. There are other potential control areas among the numerous other smaller lakes in the vicinity. Five of these lakes were selected for examination along with the more detailed studies in Ya-Ya Lake itself.

The major objective of the study was to determine the effects

of sedimentation on various trophic levels, including fish, within a northern lake ecosystem. Other associated objectives were, on the basis of the results of the study, to provide a model whereby the impact of siltation on northern lake ecosystems can be better predicted and quantified and to propose quantitative criteria, defining acceptable levels of sedimentation, which could be used in regulating development projects in the north.

As the study progressed it became apparent that, because of the wide seasonal and annual variability in the results obtained at even individual stations as well as the variability between stations and among lakes, these objectives, particularly the latter two, could not be fully met. Difficulties in the application of the results are assessed in the Conclusions.



DESCRIPTION OF THE STUDY AREA

DESCRIPTION OF THE STUDY AREA

The locations of Ya-Ya Lake and the five, smaller control lakes are indicated in Figure 1, along with the locations of sampling sites. They lie on the southwest corner of Richards Island, between East and Middle Channels, in the Mackenzie River Delta.

The study area lies wholly within the Arctic Coastal Plain (Douglas, 1970) and varies in relief from less than 1 m to approximately 76 m above sea level with a median altitude of approximately 30 m. Ya-Ya Lake, at its southwestern end, lies within the floodplain of the Mackenzie River and has a lake surface elevation only 4.6 m above sea level.

Ya-Ya Lake is one of the largest lakes in the Mackenzie Delta, having an area of 20.4 km², a volume of $1.77 \times 10^8 \text{ m}^3$, and a maximum length of 18.4 km. The lake consists of a shallow turbid South Basin heavily influenced by the Mackenzie River and a deep, clear, oligotrophic North Basin. An inlet and an outlet channel occur in the west end of the South Basin. Prior to 1969, the only link between the South Basin and the Mackenzie River was via the Ya-Ya River to Harry Channel (Slaney, 1974). An exchange of water from Harry Channel to the South Basin occurred whenever Ya-Ya River flow was backed up by prolonged onshore winds from the Beaufort Sea. In 1969, a second connection between Ya-Ya Lake and the Mackenzie River formed when breakup ice opened a channel between the South

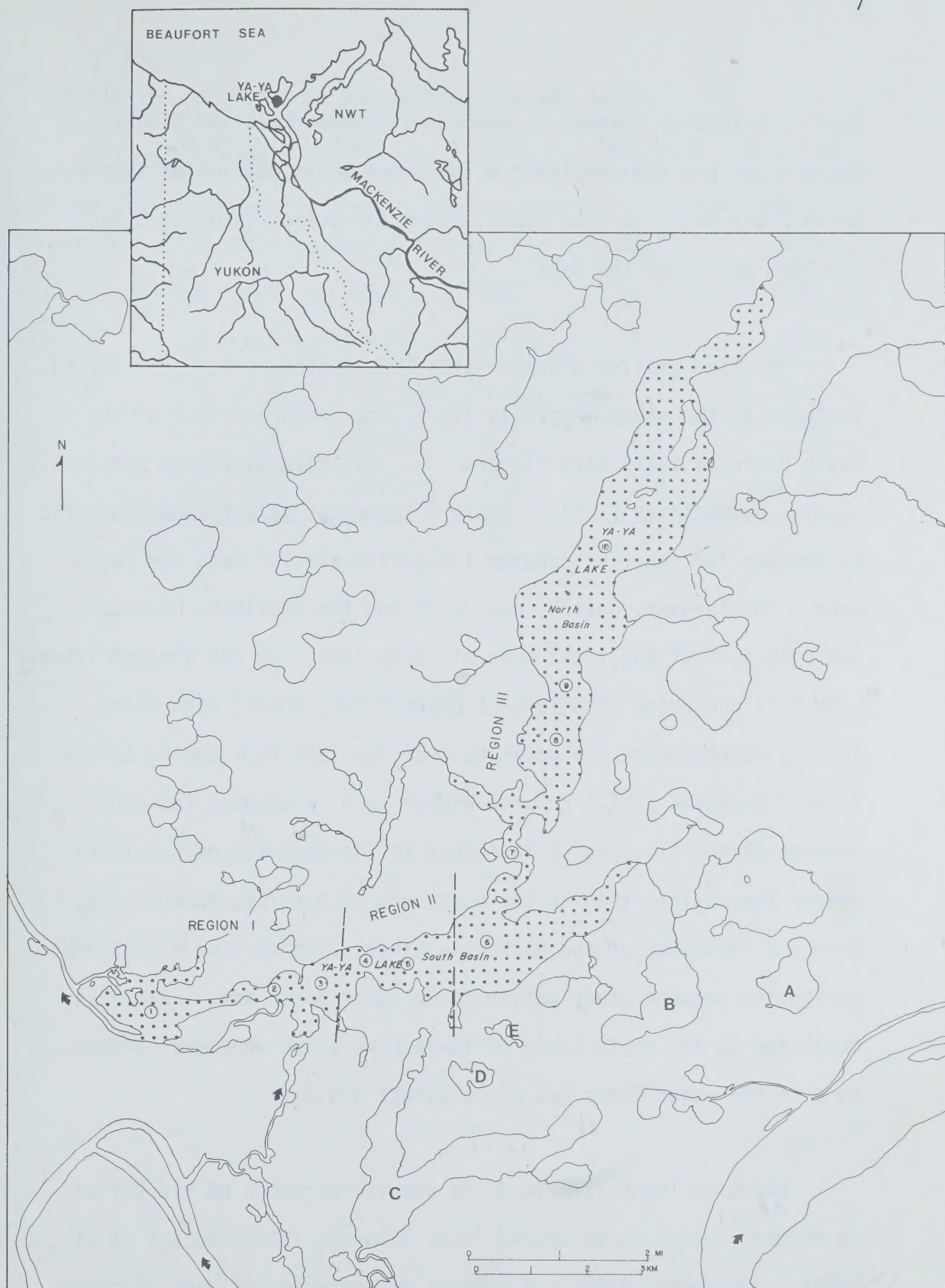


Figure 1. Location of Ya-Ya Lake and the five, smaller control lakes. Sampling stations in Ya-Ya Lake are numbered 1 to 10 and regional divisions are indicated.

Basin and Tununuk Channel, a connector between East and Middle Channels. This has resulted in increased sedimentation of the South Basin with, in some years, minor intrusions into the clearer northern region of the lake.

The five smaller unnamed lakes (designated A, B, C, D, and E) included in the study generally lie to the south and east of the South Basin of Ya-Ya Lake (Figure 1). All five have been previously studied by Machniak (1977). Table 1 compares selected morphometric parameters for the five unnamed lakes with similar data for Ya-Ya Lake. The largest, Lake C, has 26.8% and the smallest, Lake E, has only 1.2% of the total area of Ya-Ya Lake. Of the unnamed lakes, Lake C is connected with Tununuk Channel and, during high water levels, water apparently backs up into the lake from the Mackenzie River. Machniak (1977) reports higher total suspended sediment concentrations (10.3 mg/L) in August in the east arm of the lake, nearer the outlet, than in the north arm (2.5 mg/L), further away from the influence of the Mackenzie River. The station established during the present study was in the clearer north arm. Lake B is connected to the South Basin of Ya-Ya Lake by an ephemeral stream. None of the other lakes has any distinct drainage.

Lakes in the Mackenzie Delta and vicinity can be classified as either *floodplain* or *upland* lakes (Slaney, 1974; McCart et al., 1976). *Floodplain lakes* are subject to periodic influxes of silt and nutrient-laden river water either by inundation or, in some

Table 1. Morphometric parameters of study lakes.

Lake	Depth (m)		Area (ha)	Volume (m ³ x 10 ⁶)	Perimeter (km)	Shoreline Development (D _L)
	Mean	Max.				
Ya Ya	8.7	48.8	2037.8	177.2	64.7	3.98
A	3.4	4.0	79.5	2.7	5.4	1.71
B	2.8	3.5	166.6	4.7	8.3	1.18
C	3.6	27.4	448.1	16.1	18.7	2.49
D	1.0	1.3	29.8	0.3	2.7	1.39
E	2.0	2.5	24.9	0.5	2.0	1.13

cases, by virtue of connections to river channels. Such lakes are highly variable in the amount of river water they receive. Those directly connected to river channels receive influxes of river water whenever channel levels reach sufficient height for lakeward flow to occur. Some of these channel-connected lakes are located in upland terrain on the edge of the floodplain and may resemble upland lakes in some morphometric parameters. Some floodplain lakes, being integral parts of river channels, receive an almost continuous flow of river water. On the other hand, floodplain lakes may be separated from river channels by levees that are high enough to prevent flooding during some years (Mackay, 1963).

The relatively high turbidities that result from influxes of river water into floodplain lakes are generally maintained throughout the open water season by wind action since these lakes have silt bottoms and are typically less than 4 m deep. Bank recession due to slumping from thermokarst processes is common. The lakes are generally uniform in depth. Fish species are essentially the same ones found in river channels.

Isolated from river water, *upland lakes* are usually clear waterbodies with stable, well-vegetated banks, and bottoms that slope gently from shore. Bottom substrates are typically organic muck, although deposits of hard sandy material overlain by smooth gravel and cobbles occur in shallow areas. Emergent and submergent rooted vegetation is common. These lakes are deepest

in areas of pronounced relief and may have bottom areas with abrupt and considerable variations in depth.

Ya-Ya Lake has characteristics of both types: a shallow South Basin which is greatly affected by flooding from the Mackenzie River and a deep North Basin which is rarely, if ever, directly affected by the river. Among the unnamed lakes, C, which is directly connected to the Mackenzie River, is best classified as a floodplain lake though, like Ya-Ya Lake, large areas seem to be rarely affected. The other four lakes (A, B, D, and E) are all upland lakes.

All waterbodies in the study area are frozen over in winter. Freeze-up usually occurs about mid-October but can vary several weeks either way. During the fall of 1975 (McCart et al., 1976), freeze-up was relatively rapid. Significant ice formation began about 21 September and by 25 September many floodplain lakes and upland lakes on Richards Island had 90-100% ice cover.

Factors influencing maximum ice thickness include the severity of winter, as well as the depth, time, duration, and density of the snow cover. In general, the thicker the ice that forms during the winter, the later break-up occurs in the spring. In channels in the Mackenzie Delta, this usually occurs in late May or early June. Normally, break-up progresses downstream from headwaters to delta. Among lakes, floodplain lakes connected to river channels

are usually the first to clear while lakes in upland areas and those near the Beaufort Sea are last.

In the winter of 1975/76, McCart et al. (1976) measured ice thicknesses, in the North Basin of Ya-Ya Lake, of 77 cm in November and 161 cm in February. The mean thicknesses for 10 lakes in the immediate area were 76.3 cm (52-88 cm) in November and 155.0 cm (132-187 cm) in February. During December 1977 when Ya-Ya Lake was surveyed, ice thicknesses ranged from 1.0 to 1.6 m. In the spring of 1978, the ice on Ya-Ya Lake broke up over an approximately 2 week period between June 28 and July 12. The shallow outlet end broke up first but sheets of ice up to 0.5 m thick were still present in the North Basin as late as July 10.

WATER QUALITY

By

P.M. Cross, M.Sc.

WATER QUALITY

Introduction

The general effects of siltation on water quality have been reviewed by Ellis (1936), Cairns (1968), and Oschwald (1972). They include:

- 1) reduction of light penetration
- 2) interference with heat transmission
- 3) reduction in dissolved oxygen concentrations
- 4) adsorption and/or resuspension of nutrients and toxicants.

The objectives of this portion of the study were:

- 1) to compare the water quality and physical environment of the control and silted areas of Ya-Ya Lake, and
- 2) to compare these data with other smaller lakes in the vicinity.

Methods

Sampling stations were those indicated in Figure 1. At each station, water samples were collected at various depths with

a Kemmerer bottle. Samples were taken at the surface and bottom in shallow regions of the lake (i.e., those less than 3 m deep), and at the surface, mid-depth, and bottom in deeper waters.

The following parameters were measured:

temperature (C)

dissolved oxygen (D.O.)(mg/L)

pH

alkalinity (mg/L)

transparency (m)

turbidity (FTU)

suspended solids (mg/L)

conductivity (μ mhos/cm @ 25 C)

major ions (Ca, Mg, Na, K, Cl, SO₄, and HCO₃)(mg/L)

total phosphorous (μ g/L)

total dissolved phosphorus (TDP)(μ g/L)

total nitrogen (μ g/L)

total dissolved nitrogen (TDN)(μ g/L)

total organic carbon (TOC)(μ g/L)

soluble reactive silica (SiO₂)(μ g/L)

chlorophyll-a (μ g/L)

Analyses were performed according to the methods outlined in Table 2 .

Table 2. Preservation and analytical methods for physical, chemical and morphometric parameters.

Parameter	Preservation	Methods	Source of Method	Modifications
Temperature		Mercury pocket thermometer		
Dissolved Oxygen		Hach kit OX-10		none
pH	1 mL CuSO_4	Combined electrode type radiometer GK 2311 C	Radiometer pH meter type 296	none
Alkalinity System (HCO_3)	Chloroform (CHCl_3)	Acid titration	Standard Methods	pH meter replaces mixed indicator
Transparency		Secchi disc		
Turbidity	1 mL CuSO_4 solution	Nephelometry	Measured at FTU using a Hach Model 2100A Turbidimeter.	none
Conductivity	5 mL 4N HCl	Meter	Beckman Solu-bridge RB4-250	none
Ca	"	Atomic absorption	Instrumentation laboratories Model 151 aa/33 spectrophotometer	none
Mg	"	Atomic absorption	"	none
Na	"	Atomic absorption	"	Li suppression of ionization
K	"	Atomic absorption	"	"

(Continued)

Table 2. Continued.

Parameter	Preservation	Methods	Source of Method	Modifications
SO ₄	CHCl ₃	Turbidimetric method	Standard Methods	Plunger mixing Hach Turbidimeter Model 2100A
Cl	CHCl ₃	Argentometric titration	"	none
Phosphorus	5 mL 4N HCl	Persulphate digestion followed ascorbic acid PO ₄ method.	Standard Methods for the examination of water and wastewater. 13th Ed. (1971)	none (TDP-filtered)
Nitrogen	5 mL 4N HCl	Ultraviolet photo-chemical oxidation	Strickland and Parsons (1968)	Overnight (15 hr) irradiation period using a 550 watt lamp. TDN-filtered.
TOC	frozen	Infrared spectroscopy	Beckman Carbonaceous Analyser Model 915. Inland Waters Directorate, Analytical Methods Manual, Water Quality Branch, Environment Canada, Ottawa.	
SiO ₂	CHCl ₃	Heteropoly blue	Standard Methods	none
Chlorophyll a	frozen filter	Trichromatic	Standard Methods	none

Results and Discussion

This report describes samples taken during three sampling periods: summer (July 29-August 5, 1977), winter (December 8-12, 1977), and spring break-up (July 6-10, 1978). The data on which the discussion is based are presented in Tables 3, 4 and 5, and summarized in various text tables and figures.

Suspended Sediments

For the purposes of discussion, the study area in Ya-Ya Lake can be divided into three regions which correspond to various degrees of siltation.

Region I (Stations 1-3) had a mean (for summer 1977 and spring 1978) total suspended sediment concentration of 119.9 mg/L and a mean turbidity of 69.3 FTU during the open water season (Table 6). Region I can be regarded as an area of maximum impact in terms of the negative effects of siltation. Hynes (1973), for example, indicated that concentrations of inert silt, sand, or clay that exceed 80 mg/L may seriously damage fisheries. Region II (Stations 4-5) had a mean total suspended sediment level of 17.6 mg/L and a mean turbidity of 14.5 FTU. Brunskill et al. (1973) suggested a tentative "critical level" of suspended sediments of 15 mg/L over which benthic fauna were reduced in numbers and diversity in the Mackenzie River watershed. Region II, where the mean exceeds this critical value, can be regarded

Table 3. Physical and chemical data for Ya-Ya Lake and five small nearby lakes.

Station/Date	Sample Depth (m)	Temp. (°C)	D.O. (mg/L)	Per cent O ₂ Saturation	Alkalinity (mg/L)	Secchi Disc		Turbidity (FTU)	Susp. Sediments (mg/L)
						pH	Transparency (m)		
1 3/ 8/77	surface	18.0	9.2	97	90	7.7	0.05	140.0	223.0
	bottom (2.0)	18.0	9.2	97	87	7.8	-	165.0	274.0
12/12/77	surface	0	13.8	94			-		
7/ 7/78	surface	14.5	10.8	106	74	7.5	0.1	65.0	105.2
	bottom (2.0)	14.5	11.0	106	77	7.7	-	82.0	127.2
2 2/ 8/77	surface	16.0	9.2	94	85	7.8	0.10	65.0	105.3
	middle (2.5)	16.0	9.3	95	81	7.8	-	73.0	121.3
	bottom (5.3)	16.0	9.2	94	85	7.8	-	54.0	85.3
12/12/77	surface	0	13.8	94					
7/ 7/78	surface	15.0	11.4	112	76	7.8	0.1	60.0	106.8
	bottom (2.1)	15.0	11.4	112	74	7.7	-	55.0	113.2
3 2/ 8/77	surface	16.5	9.6	99	89	7.9	0.40	13.0	14.4
	bottom (1.9)	16.5	9.4	96	90	7.8	-	12.0	14.4
11/12/77	surface	0	13.8	94					
7/ 7/78	surface	15.5	10.6	105	78	7.8	0.1	57.5	151.2
	bottom (2.5)	16.0	10.8	109	77	7.8	-	60.0	116.8

(Continued)

Table 3. Continued.

Station/Date	Sample Depth (m)	Temp. (°C)	D.O. (mg/L)	Percent O ₂ Saturation	Alkalinity (mg/L)	Secchi Disc			Susp. Sediments (mg/L)
						pH	Trans- parency (m)	Turbidity (FTU) (Shaken) (Settled)	
4	3/ 8/77	17.0	9.6	99	88	7.9	0.20	21.0	25.2
		17.0	9.6	99	85	7.8	-	26.0	36.8
11/12/77	surface	0	13.8	94					
	bottom(2.4)	0	13.2	89					
6/ 7/78	surface	6.0	12.2	98	69	7.5	1.0	6.2	7.9
	bottom(2.2)	6.0	12.4	100	64	7.5	-	5.5	5.0
5	2/ 8/77	16.0	9.0	91	88	7.8	0.5	11.0	10.4
		16.0	9.0	91	91	7.9	-	12.0	8.0
10/12/77	surface	0	14.0	95					
	bottom(2.5)	0	13.4	91					
8/ 7/78	surface	12.5	10.8	102	70	7.4	0.3	22.0	31.3
	bottom(2.4)	12.0	11.0	102	68	7.9	-	12.0	16.0
6	31/7/77	16.5	9.4	96	91	7.9	0.55	6.7	4.0
		16.5	9.4	96	89	7.9	-	11.0	10.6
		16.5	9.4	96	91	7.9	-	10.0	7.7
10/12/77	surface	0.0	14.0	95					
	bottom(2)	0.0	13.5	91					

(Continued)

Table 3. Continued.

Station/Date	Sample Depth (m)	Temp. (°C)	D.O. (mg/L)	Percent O ₂ Saturation	Alkalinity (mg/L)	Secchi Disc		pH	Trans- parency (m)	Turbidity (FTU)		Susp. Sediments (mg/L)
										(Shaken)	(Settled)	
6/ 7/78	surface	6.5	12.0	97	68	7.7	1.2	7.7	1.2	4.0	2.0	3.3
	middle(3.0)	6.0	12.2	98	64	7.7	-	7.7	-	5.0	2.0	7.0
	bottom(5.5)	6.0	12.0	96	66	7.7	-	7.7	-	10.0	2.5	20.4
7 30/7/77	surface	16.0	9.2	94	87	8.0	0.8	8.0	0.8	6.0	4.6	2.9
	middle(1.5)	16.0	9.3	95	92	8.0	-	8.0	-	5.6	3.8	4.0
	bottom(3.1)	16.0	9.4	95	94	7.9	-	7.9	-	6.7	4.4	5.4
9/12/77	surface	0	14.0	95								
	middle	0	14.0	95								
	bottom(5)	0	14.0	95								
6/ 7/78	surface	7.0	11.8	97	68	7.8	2.0	7.8	2.0	2.5	2.5	9.4
	middle(2.0)	7.0	12.0	99	74	7.6	-	7.6	-	2.0	1.0	3.6
	bottom(3.8)	6.5	12.0	97	74	7.9	-	7.9	-	2.5	1.0	3.6
8 29/ 7/77	surface	15.0	9.4	93	103	8.0	1.60	8.0	1.60	1.9	1.2	2.3
	middle(2.2)	13.5	9.6	92	103	8.0	-	8.0	-	1.6	1.3	1.4
	bottom(4.5)	13.0	10.0	96	96	8.1	-	8.1	-	1.3	0.7	1.7
9/12/77	surface	0	14.2	96								
	middle	0	14.0	95								
	bottom(4)	0	14.0	95								

(Continued)

Table 3. Continued.

Station/Date	Sample Depth (m)	Temp. (°C)	D.O. (mg/L)	Percent O ₂ Saturation	Alkalinity (mg/L)	Secchi Disc			Susp. Sediments (mg/L)
						pH	Trans- parency (m)	Turbidity (FTU) (Shaken) (Settled)	
9/ 7/78	surface	7.5	12.0	100	70	7.6	2.9	5.0	11.1
	middle	7.5	12.4	103	76	7.7	-	7.5	21.0
	bottom(4.4)	6.5	12.4	100	80	7.75	-	7.5	4.3
9 31/ 7/77	surface	15.5	10.8	108	101	7.9	4.30	1.1	0.9
	middle(2.1)	15.0	10.7	106	104	7.9	-	1.0	0.3
	bottom(4.3)	15.0	10.6	105	96	7.9	-	1.1	1.4
8/12/77	surface	0	14.0	95					
	middle	0	13.8	94					
	bottom(5)	0	14.0	95					
10/ 7/78	surface	4.0	12.8	97	84	7.9	4.1	2.5	5.4
	middle	5.0	12.4	97	84	7.8	-	2.5	2.2
	bottom(5.0)	5.0	12.6	98	84	7.9	-	2.5	8.8
10 1/ 8/77	surface	14.0	10.6	103	94	8.0	5.1	0.8	0.6
	middle(23.0)	8.0	11.3	95	102	7.9	-	0.8	0.9
	bottom(46.6)	6.0	12.4	100	101	7.8	-	0.5	0.9
8/12/77	surface	0	13.8	94					
	middle(5)	0	13.8	94					
	bottom(10)	0.5	13.6	94					

(Continued)

Table 3. Continued.

Station/Date	Sample Depth (m)	Temp. (°C)	D.O. (mg/L)	Percent O ₂ Saturation	Alkalinity (mg/L)	pH	Secchi Disc Transparency (m)		Turbidity (FTU)		Susp. Sediments (mg/L)
									(Shaken)	(Settled)	
10/ 7/78	surface	3.0	12.8	95	80	7.7	6.2		2.25	1.5	4.6
	middle	3.5	12.8	96	98	7.7	-		1.5	1.0	1.3
	bottom(37.5)	3.5	12.8	96	100	7.7	-		1.2	0.9	0.9
A 5/ 8/77	surface	18.5	11.0	117	39	7.0	bottom		1.3	1.0	0.3
	bottom(2.9)	18.5	11.0	117	37	7.2	-		2.0	1.1	4.6
B 5/ 8/77	surface	18.0	10.5	111	34	7.1	bottom		1.4	0.9	1.1
	bottom(2.0)	18.0	10.5	111	33	7.4	-		1.7	0.9	2.3
C 5/ 8/77	surface	17.0	11.2	115	81	7.3	1.7		5.1	2.9	3.4
	middle(4.5)	13.0	11.6	110	71	7.4	-		7.1	4.4	3.1
	bottom(9.4)	11.0	12.2	110	85	7.2	-		4.5	4.2	1.7
D 5/ 8/77	surface	20.0	8.5	94	44	6.9	1.1		3.4	2.2	3.2
E 5/ 8/77	surface	18.5	9.0	96	51	7.3	2.9		1.2	0.8	1.7
	bottom(2.9)	18.5	9.0	96	51	7.2	-		1.3	0.9	0.9

Table 4. Nutrient and Chlorophyll a data for Ya-Ya Lake and five small nearby lakes.

Station/Date	Sample Depth (m)	Phosphorus (µg/L)		Nitrogen (µg/L)		TOC (mg/L)	SiO ₂ (µg/L)	Chl a (µg/L)
		(Total)	(Diss.)	(Total)	(Diss.)			
1 3/ 8/77	surface	156	14	222	208	15	2000	5
	bottom(2.0)	128	15	234	202	-	2000	1
12/12/77	surface	14	13	230	80	13	-	-
7/ 7/78	surface	98		540		18		<1.0
	bottom(2.0)	144		320		19		<1.0
2 2/ 8/77	surface	159	11	222	207	10	2000	2
	middle(2.5)	180	12	214	215	-	2000	<1
	bottom(5.3)	185	20	176	170	-	2280	0
12/12/77	surface	12	11	238	198	12	-	-
7/ 7/78	surface	331		400		13		<1.0
	bottom(2.1)	98		340		9		<1.0
3 2/ 8/77	surface	15	<10	208	166	10	1960	3
	bottom(1.9)	67	<10	219	207	-	1860	1
11/12/77	surface	20	<10	216	176	14	-	-
7/ 7/78	surface	185		320		14		<1.0
	bottom(2.5)	152		320		8		<1.0

(Continued)

Table 4. Continued.

Station/Date	Sample Depth (m)	Phosphorus ($\mu\text{g/L}$)		Nitrogen ($\mu\text{g/L}$)		TOC (mg/L)	SiO_2 ($\mu\text{g/L}$)	Chl a ($\mu\text{g/L}$)
		(Total)	(Diss.)	(Total)	(Diss.)			
4	3/ 8/77	29	<10	202	191	8	1960	4
		63	12	198	189	-	1880	2
11/12/77	surface	19	11	230	170	17	-	-
		20	<10	228	198	13	-	-
6/ 7/78	surface	17	-	190	-	<1	-	<1.0
		16	-	240	-	20	-	<1.0
5	2/ 8/77	19	<10	207	202	10	1760	3
		73	<10	219	213	-	1780	2
10/12/77	surface	19	<10	272	234	17	-	-
		25	<10	238	204	18	-	-
8/ 7/78	surface	36	-	240	-	14	-	<1.0
		38	-	170	-	11	-	<1.0
6	31/ 7/77	41	<10	198	189	-	1740	3
		40	12	163	152	4	1800	2
		28	21	207	182	8	1840	-
10/12/77	surface	17	12	304	250	17	-	-
		14	11	282	240	14	-	-

(Continued)

Table 4. Continued.

Station/Date	Sample Depth (m)	Phosphorus		Nitrogen		TOC (mg/L)	SiO ₂ (μg/L)	Chl a (μg/L)
		(Total)	(Diss.)	(Total)	(Diss.)			
6/ 7/78	surface	20		270		13		<1.0
	middle(3.0)	17		190		5		<1.0
	bottom(5.5)	65		270		2		<1.0
7 30/ 7/77	surface	37	11	198	178	-	1840	1
	middle(1.5)	29	12	198	190	5	1720	2
	bottom(3.1)	36	<10	195	187	8	1760	-
9/12/77	surface	<10	<10	278	258	16		-
	middle	<10	<10	256	226	13		-
	bottom(5)	24	17	262	234	14		-
6/ 7/78	surface	15		200		3		<1.0
	middle(2.0)	23		190		-		<1.0
	bottom(3.8)	28		260		19		<1.0
8 29/ 7/77	surface	12	<10	160	158	23	1760	2
	middle(2.2)	11	<10	163	159	10	1720	2
	bottom(4.5)	49	26	172	160	9	1620	-
9/12/77	surface	27	<10	262	222	17		-
	middle	18	<10	252	180	14		-
	bottom(4)	23	20	234	216	11		-

(Continued)

Table 4. Continued.

Station/Date	Sample Depth (m)	Phosphorus		Nitrogen		TOC (mg/L)	SiO ₂ (μg/L)	Chl a (μg/L)
		(Total)	(Diss.)	(Total)	(Diss.)			
9/ 7/78	surface	98		200		8		<1.0
	middle	24		220		12		<1.0
	bottom(4.4)	10		210		19		<1.0
9 31/ 7/77	surface	23	12	189	166	10	1820	2
	middle(2.1)	43	16	184	173	-	1760	1
	bottom(4.3)	33	35	184	171	-	1820	-
8/12/77	surface	15	<10	268	222	12		-
	middle	24	<10	244	234	13		-
	bottom(5)	21	<10	260	244	14		-
10/ 7/78	surface	14		280		12		<1.0
	middle	9		220		1		<1.0
	bottom(5.0)	15		170		31		<1.0
10 1/ 8/77	surface	<10	<10	178	173	10	1820	2
	middle(23.0)	<10	<10	189	171	-	1880	2
	bottom(46.6)	21	<10	189	178	-	1980	-
8/12/77	surface	22	11	244	226	12		-
	middle(5)	19	<10	218	188	23		-
	bottom(10)	108	21	250	222	23		-

(Continued)

Table 4. Continued.

Station/Date	Sample Depth (m)	Phosphorus ($\mu\text{g/L}$)		Nitrogen ($\mu\text{g/L}$)		TOC (mg/L)	SiO_2 ($\mu\text{g/L}$)	Chl a ($\mu\text{g/L}$)
		(Total)	(Diss.)	(Total)	(Diss.)			
10/ 7/78	surface	21		230		12		<1.0
	middle	8		290		20		<1.0
	bottom(37.5)	30		240		13		<1.0
A 5/ 8/77	surface	39	<10	314	290	6	360	2
	bottom(2.9)	31	<10	314	302	-	400	-
B 5/ 8/77	surface	16	16	254	26	5	560	4
	bottom(2.0)	53	<10	298	32	-	540	-
C 5/ 8/77	surface	21	<10	204	194	9	1620	3
	middle(4.5)	19	23	230	218	-	1400	-
	bottom(9.4)	24	11	286	226	-	1700	-
D 5/ 8/77	surface	47	19	572	460	12	800	8
E 5/ 8/77	surface	<10	21	356	344	11	360	3
	bottom(2.9)	<10	<10	338	292	-	380	-

Table 5. Conductivity and major ion data for Ya-Ya Lake and five small nearby lakes.

Station/Date	Sample Depth (m)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO ₄ (mg/L)	CO ₃ (mg/L)	HCO ₃ (mg/L)	Total (mg/L)	% Error	Cond. µmhos/ cm
1	3/ 8/77	surface bottom(2.0)	8.3 8.9	5.8 7.4	0.96 0.97	5.5 6.0	34 32	0 0	90 87	172.16 172.17	6.5 0.1	231 231
7/ 7/78	surface bottom(2.0)	32 30	7.1 7.1	5.9 6.1	0.9 1.1	11 11	26 30	<1.0 <1.0	90 94	172.90 179.30	3.7 8.5	226 215
2	2/ 8/77	surface middle(2.5) bottom(5.3)	9.3 8.4 9.4	7.7 5.8 7.1	1.00 0.96 1.01	5.5 6.5 5.5	32 42 36	0 0 0	85 81 85	171.40 173.46 173.91	-2.8 5.4 0.1	227 231 227
7/ 7/78	surface bottom(2.1)	32 32	7.3 7.2	5.8 6.3	0.9 0.9	10.0 9.0	30 25	<1.0 <1.0	93 90	179.00 170.40	5.6 1.8	210 210
3	2/ 8/77	surface bottom(1.9)	9.9 9.3	8.2 7.3	1.12 1.08	7.5 7.5	41 36	0 0	89 90	188.22 182.88	1.3 1.3	243 235
7/ 7/78	surface bottom(2.5)	34 33	7.3 7.6	6.9 6.4	0.9 1.0	9.0 15.0	28 26	<1.0 <1.0	95 94	181.10 183.00	2.2 5.0	210 210
4	3/ 8/77	surface bottom(2.2)	10.7 9.2	8.9 7.0	1.08 1.05	6.0 7.5	31 46	0 0	88 85	177.98 187.45	-6.1 3.6	237 237
6/ 7/78	surface bottom(2.2)	26 26	6.0 6.1	6.5 8.2	0.9 0.9	11.0 13.0	20 23	<1.0 <1.0	84 78	154.40 155.20	6.9 4.9	194 183

(Continued)

Table 5. Continued.

Station/Date	Sample Depth (m)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO ₄ (mg/L)	CO ₃ (mg/L)	HCO ₃ (mg/L)	Total (mg/L)	% Error	Cond. µmhos/ cm
5	2/ 8/77 surface bottom(2.0)	31.9	9.7	8.5	1.14	7.5	34	0	88	180.74	-2.0	239
		32.3	9.6	7.5	1.20	7.5	31	0	91	180.10	-1.5	238
8	7/78 surface bottom(2.4)	27	6.3	8.5	0.9	11	22	<1.0	85	160.70	4.5	199
		27	6.3	6.4	1.0	9	26	<1.0	83	158.70	6.2	194
6	31/ 7/77 surface middle(2.8) bottom(5.4)	30.5	9.5	8.1	1.15	8.5	32	2	89	180.75	0.8	231
		30.3	9.5	9.0	1.12	9.0	31	0	89	178.92	-0.6	231
		32.3	9.6	8.5	1.16	10.5	41	0	91	194.06	2.9	237
6	7/78 surface middle(3.0) bottom(5.5)	27	6.3	6.8	1.0	9.0	25	<1.0	83	158.10	5.4	190
		25	6.1	7.6	1.0	11.0	23	<1.0	78	151.70	5.5	194
		25	6.0	6.5	1.0	10.0	23	<1.0	80	151.50	7.1	199
7	30/ 7/77 surface middle(1.5) bottom(3.1)	30.3	9.5	8.5	1.20	9.5	42	0	87	188.00	3.4	247
		31.7	9.5	9.3	1.18	9.0	30	0	92	182.68	-1.4	245
		33.1	9.4	8.4	1.18	22.0	42	0	94	210.08	8.9	247
6	7/78 surface middle(2.0) bottom(3.8)	29	7.0	7.4	1.1	16	24	<1.0	83	167.50	4.8	220
		30	6.7	7.6	1.1	13	21	<1.0	90	169.40	3.9	215
		30	6.7	7.9	1.1	13	25	<1.0	90	173.70	5.2	210
8	29/ 7/77 surface middle(2.2) bottom(4.5)	35.5	10.5	10.8	1.32	12.0	34	6	97	207.12	-0.5	272
		33.1	9.8	9.9	1.32	27.5	34	0	103	218.62	9.6	272
		35.3	10.2	9.5	1.26	12.0	46	8	88	210.26	2.7	272

(Continued)

Table 5. Continued.

Station/Date	Sample Depth (m)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO ₄ (mg/L)	CO ₃ (mg/L)	HCO ₃ (mg/L)	Total (mg/L)	% Error	Cond. µmhos/ cm
9/ 7/78	surface	30	7.0	7.8	1.2	11	24	<1.0	85	166.00	1.4	215
	middle	31	7.2	7.8	1.1	11	23	<1.0	93	174.10	2.8	220
	bottom(4.4)	31	7.3	7.6	1.1	23	16	<1.0	98	184.00	8.0	220
9 31/ 7/77	surface	35.3	10.9	10.7	1.32	11.5	41	0	101	211.72	0.6	273
	middle(2.1)	34.1	10.1	10.3	1.32	11.0	32	0	104	202.82	0.7	273
	bottom(4.3)	34.5	9.9	23.3	1.32	16.0	46	0	96	227.02	-3.7	278
10/ 7/78	surface	36	8.3	8.8	1.3	9	30	<1.0	102	195.40	0.4	253
	middle	34	8.2	8.8	1.2	13	27	<1.0	102	194.20	3.2	253
	bottom(5.0)	37	8.1	9.4	1.2	13	30	<1.0	102	200.70	1.3	247
10 1/ 8/77	surface	36.8	11.6	12.3	1.34	11.5	36	0	94	203.54	-6.4	275
	middle(23.0)	34.5	10.7	10.8	1.32	11.5	34	0	102	204.82	-0.5	278
	bottom(46.6)	37.6	11.1	12.3	1.30	11.0	46	0	101	220.30	-1.0	282
10/ 7/78	surface	32	7.5	7.8	1.1	10	25	<1.0	98	181.40	3.4	231
	middle	42	9.6	10.0	1.3	17	32	<1.0	119	230.90	2.5	280
	bottom(37.5)	42	9.6	9.6	1.4	20	31	<1.0	122	235.60	4.5	290
A 5/ 8/77	surface	11.0	5.4	7.0	1.26	8.5	<1	0	39	66.76	-13.2	103
	bottom(2.9)	10.6	4.7	5.5	1.12	8.5	<1	0	37	67.42	-9.4	103
B 5/ 8/77	surface	17.3	6.1	6.4	0.90	8.5	<1	0	34	73.20	-28.9	94
	bottom(2.0)	11.6	5.2	4.9	0.80	8.0	<1	0	33	63.50	-16.7	121

(Continued)

Table 5. Continued.

Station/Date	Sample Depth (m)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO ₄ (mg/L)	CO ₃ (mg/L)	HCO ₃ (mg/L)	Total (mg/L)	% Error	Cond. µmhos/ cm
C	5/ 8/77	surface	29.4	8.2	6.4	1.01	6.0	26	81	158.01	-2.4	221
		middle(4.5)	31.1	8.6	7.4	1.02	7.5	18	71	144.62	-13.0	236
		bottom(9.4)	29.6	8.2	6.4	1.05	6.0	37	85	173.25	3.6	221
D	5/ 8/77	surface	12.8	7.5	5.5	1.28	8.5	5	44	84.58	-11.0	125
E	5/ 8/77	surface	22.3	9.1	5.5	1.11	9.5	32	51	130.51	-4.3	209
		bottom(2.9)	23.4	9.7	6.4	1.06	9.0	55	51	155.56	3.1	198

Table 6. Summary of summer and spring data for selected parameters illustrating regional differences in water quality. Means are calculated for all samples within each Region.

	Region I		Region II		Region III	
	Mean	Range	Mean	Range	Mean	Range
Suspended solids (mg/L)						
summer	119.7	14.4-274.0	20.1	8.0- 36.8	3.0	0.3- 10.6
spring	120.1	105.2-151.2	15.1	5.0- 31.3	7.1	0.9- 21.0
summer & spring	119.9		17.6		5.1	
Turbidity (shaken) (FTU)						
summer	74.6	12.0-165.0	17.5	11.0- 26.0	3.7	0.5- 11.0
spring	63.2	55.0- 82.0	11.4	5.5- 22.0	3.9	1.2- 10.0
summer & spring	69.3		14.5		3.8	
Turbidity (settled) (FTU)						
summer	9.1	4.5- 15.0	6.0	5.2- 7.0	2.3	0.3- 5.7
spring	13.9	10.0- 16.0	4.8	2.5- 8.0	1.8	0.9- 5.0
summer & spring	11.3		5.4		2.0	
Secchi disc transparency (m)						
summer	0.18	0.05- 0.40	0.35	0.2- 0.5	2.47	0.55- 5.1
spring	0.10	0.10	0.65	0.3- 1.0	3.28	1.2- 6.2
summer & spring	0.14		0.50		2.88	
Total phosphorus ($\mu\text{g/L}$)						
summer	127.1	15 -185	46.0	19- 73	28.2	<10 - 49
spring	168.0	98 -331	26.8	16- 38	26.5	8 - 98

(Continued)

Table 6. Continued.

	Region I		Region II		Region III	
	Mean	Range	Mean	Range	Mean	Range
Total phosphorus ($\mu\text{g/L}$)						
summer & spring	146.0		36.4		27.3	
Total nitrogen ($\mu\text{g/L}$)						
summer	213.6	176-234	206.5	198-219	184.5	160-207
spring	373.3	320-540	210.0	170-240	229.3	170-290
summer & spring	287.3		208.3		206.9	

as an area of moderate impact, though still clearly within the zone of influence.

Region III (Stations 6-10) can be considered as a non-impacted or "control" area. Mean levels of total suspended sediments and turbidity were 5.1 mg/L and 3.8 FTU, respectively.

A comparison of the combined summer (July 29-August 5, 1977), and spring (July 6-10, 1978) data indicates that the suspended sediment concentrations in these regions differ significantly ($t=4.033$, 9.015 , and 4.436 ; $P<0.05$: for comparisons between Regions I and II, I and III, and II and III, respectively). The patterns of suspended sediment concentrations in Region I is, however, different in summer and in spring (Figure 2). In summer, the concentration decreases rapidly from Station 1 through 3 while in spring, there is a more uniform regional concentration. This seasonal difference is probably the result of hydrological conditions. The higher discharge during spring break-up causes more water to back up within the lake and there is a greater degree of mixing within the region.

There are no data describing suspended sediment concentrations during the winter sampling period of this study; however, they are probably uniformly low. The Mackenzie River, the source of most of the suspended sediments in the outlet end of the lake is itself quite clear during the fall and winter under cover of ice.

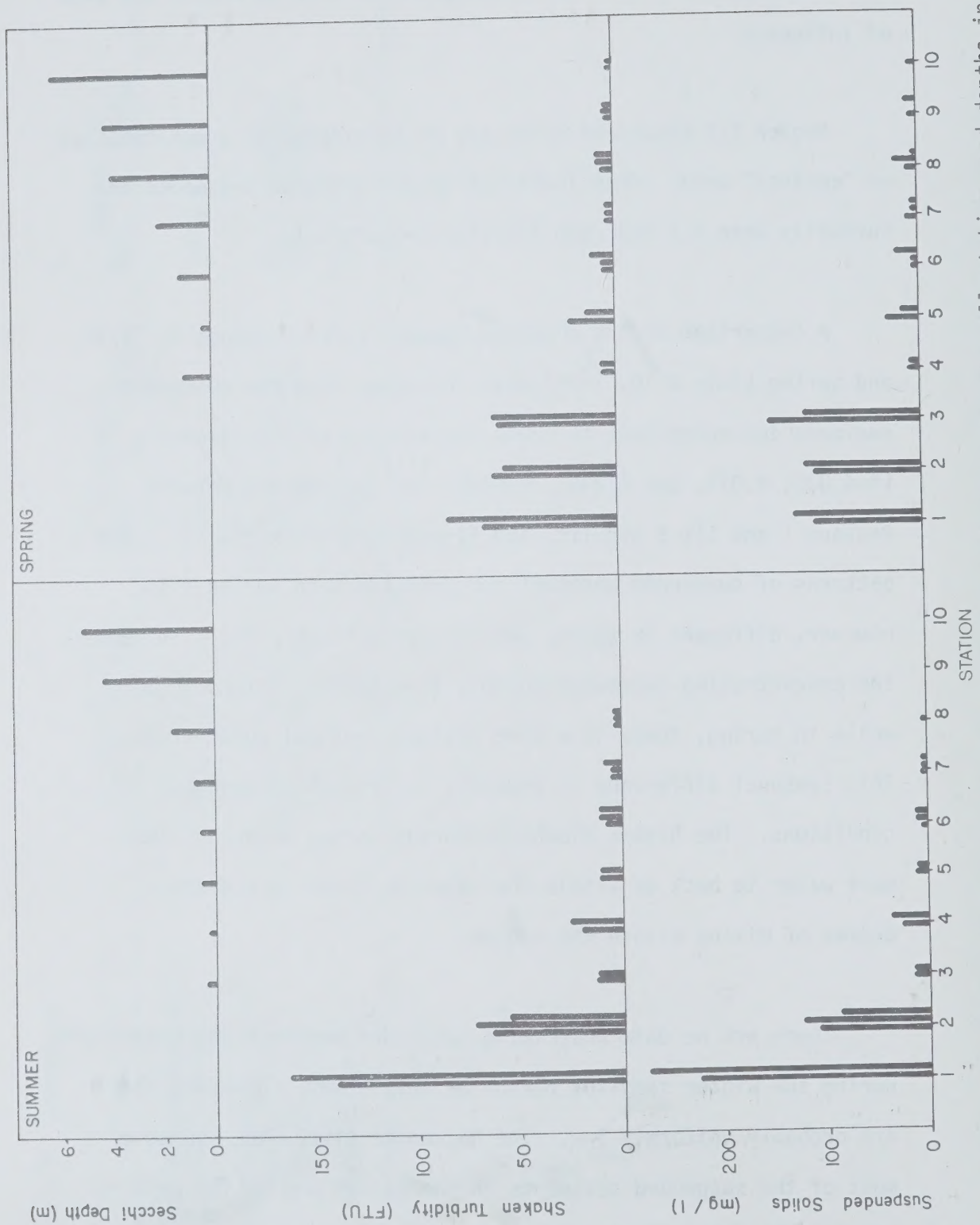


Figure 2. Suspended solids, shaken turbidity, and Secchi depth data for all stations and depths in Va-Va Lake during summer 1977 and spring 1978. Surface, midwater, and bottom samples are

McCart et al. (1976) measured suspended sediment concentrations of <1.0 to 1.5 mg/L in the North Basin of Ya-Ya Lake on September, November, and February sampling dates. Their sampling location is in the same area as Station 10 of this study and the values they recorded are similar to those recorded at Station 10 during the summer and spring. de Graaf and Machniak (1977) recorded a value of only 12 mg/L on the river channel which drains into Ya-Ya Lake as early as September 22, 1976. On April 2, 1975, under late winter ice, Mann (1975) recorded a suspended sediment concentration of 9.1 mg/L in the Ya-Ya River which drains Ya-Ya Lake. Concentrations in the lake itself, where there is little or no winter flow, would be expected to be even lower.

Secchi Disc Transparency and Turbidity

Secchi Disc transparencies recorded during the summer and spring were very low in Regions I and II but increasingly greater at stations in Region III (Figure 2 and Table 6). Secchi depths were not recorded during the winter because of the lack of light. There was a curvilinear relationship between Secchi values and suspended sediment concentrations for data from the study area (Figure 3) similar to one previously described by McCart et al. (1976) for other lakes in the Richards Island/Parsons Lake area.

Values for shaken turbidity had a pattern of distribution during both summer and spring which was similar to that for suspended sediments (Figure 2). The two parameters were highly

correlated for samples from both the summer of 1977 ($r=0.999$, $N=26$) and the spring of 1978 ($r=0.971$, $N=21$) but the relationships for the two seasons differed significantly in both slopes ($F=15.50$, $P<0.05$) and adjusted means ($F=9.62$, $P<0.05$). Neither the summer nor the spring relationship was like the overall relationship which McCart et al. (1976) calculated for 23 floodplain lakes in the Richards Island area (Figure 3).

The relationship of settled turbidity to shaken turbidity is illustrated by station in Figure 4. In both the summer and spring sampling periods, settled turbidity constituted only a small proportion (less than 25%) of the shaken turbidity at Stations 1 and 2 where suspended sediment loads and turbidities were highest. This proportion generally increased with distance uplake and in Region III (Stations 6-10), settled turbidity ranged from about 40 to 70% of shaken turbidity. The probable explanation is that in Region I (Stations 1 through 3), where currents are detectable throughout the open water season, settleable sediments are kept in suspension and therefore constitute a relatively high proportion of the total turbidity.

No turbidity data are available for the winter period but, like suspended sediment concentrations, turbidities are expected to be low and relatively uniform throughout the lake.

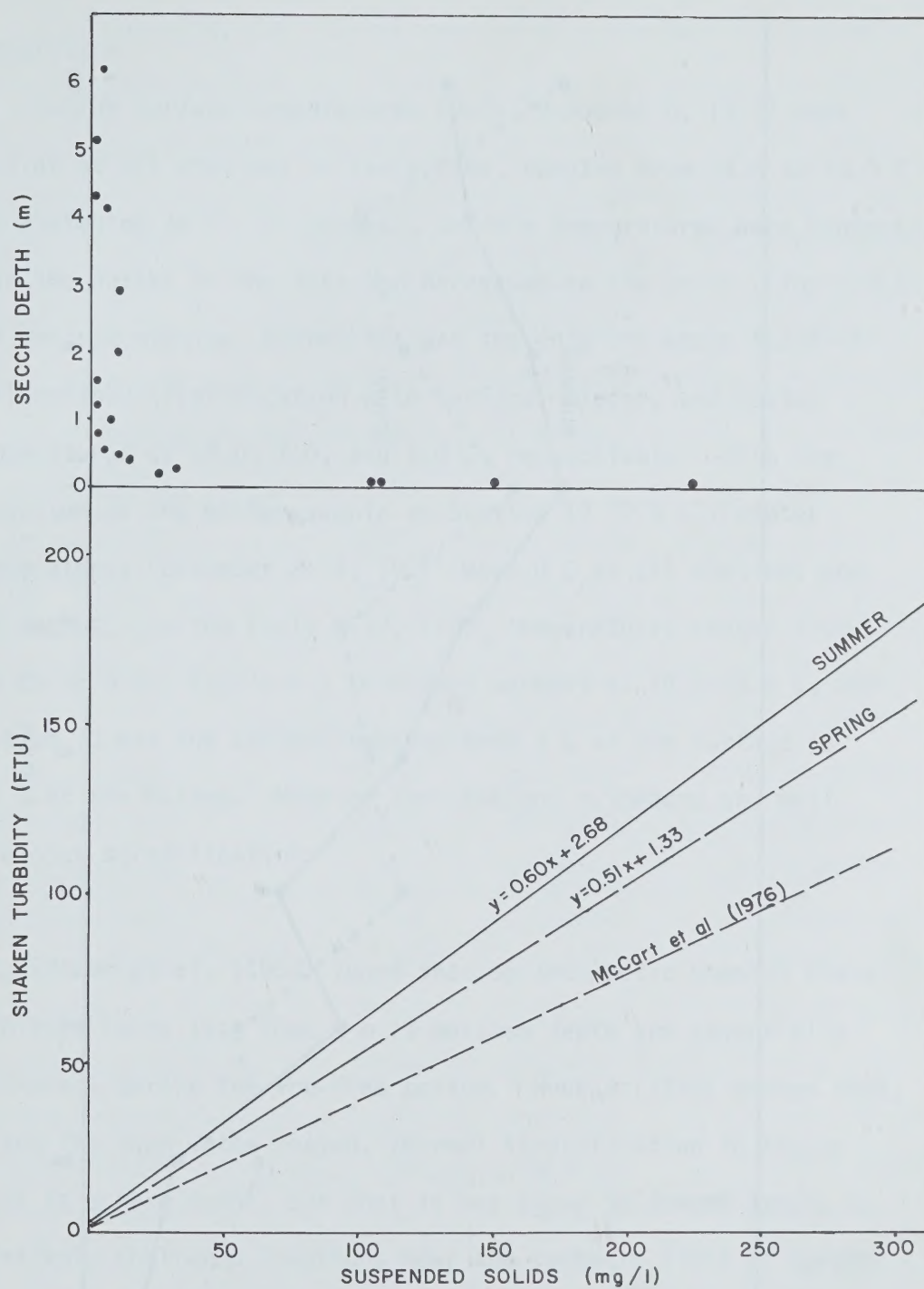


Figure 3. Relationships between suspended solids and shaken turbidity and between suspended solids and Secchi depth. Data from all stations at all depths are included for summer 1977 and spring 1978.

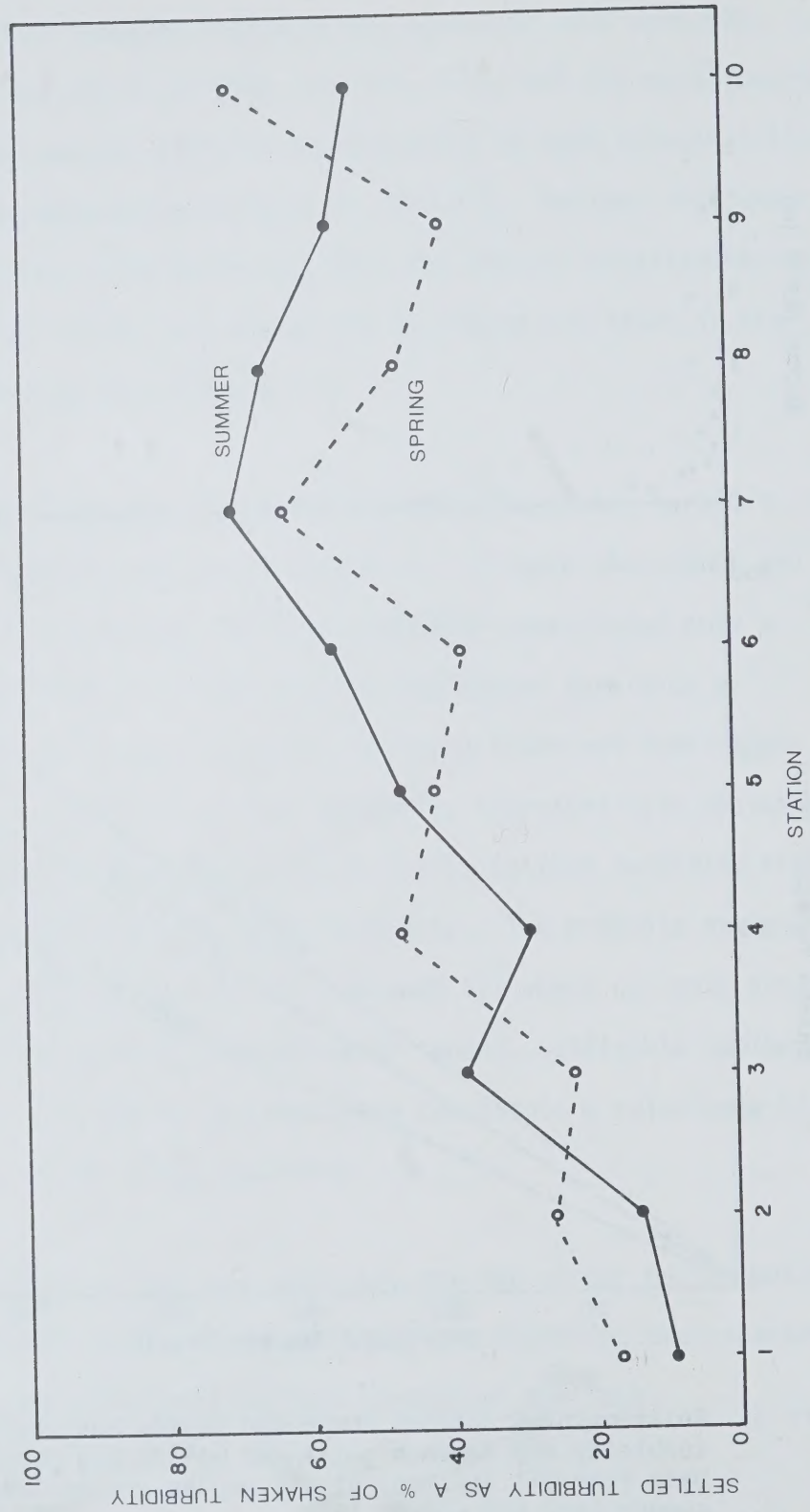


Figure 4. Settled turbidity as a per cent of shaken turbidity for Ya-Ya Lake. Surface samples were used at each of 10 stations using data from summer 1977 and spring 1978.

Temperature

Summer surface temperatures (July 29-August 5, 1977) were similar at all stations in Ya-Ya Lake, ranging from 14.0 to 18.0 C and averaging 16 C. In general, surface temperatures were highest near the outlet of the lake and decreased to the north (Figure 5). The deepest station, Number 10, was the only one where there was well-defined stratification with surface, middle, and bottom temperatures of 14.0, 8.0, and 6.0 C, respectively. With the exception of the bottom sample at Station 10 (0.5 C), winter temperatures (December 8-12, 1977) were 0 C at all stations and all depths. Spring (July 6-10, 1978) temperatures ranged from 3.0 to 16.0 C. Stations 1 to 3 were warmest at 14.5-16.0 C, and Station 10 was the coldest ranging from 3 C at the surface to 3.5 C at the bottom. None of the stations evidenced any well developed stratification.

Brewer et al. (1958) found that on the Arctic Coastal Plain in Alaska lakes less than 4 m in maximum depth are essentially isothermal during the ice-free period. Hobbie (1973) states that, during the open water season, thermal stratification in Arctic lakes is a rare event, but that it may occur in deeper lakes, in relatively sheltered locations near the southern limit of tundra, during warm and calm summers.

Nine of the 10 sampling stations at Ya-Ya Lake lie in the shallow South Basin. Of the nine stations, only four exceed 4 m

in depth and none are greater than 5.5 m. The southern basin lies within an area of generally low relief and is exposed to prevailing winds. This, in combination with the flush of Mackenzie River water which moves through the shallow basin during the spring and early summer, may well reduce the probability of stable stratification developing there. In contrast, the northern basin is deeper (approximately 46.6 m), lies in an area of greater relief, and is not subject to flushing by Mackenzie River water. This basin was stratified at Station 10 on August 1, 1977. In 1975, however, samples taken September 18 in the North Basin were isothermal at 8 C to a depth of 18.6 m (McCart et al., 1976). If the North Basin did stratify in 1975, it is likely that the stratification had broken down by mid-September.

Dissolved Oxygen

Dissolved oxygen concentrations were high throughout the lake during each of the sampling periods, never falling below 9 mg/L and 89% saturation even during the winter (Figure 5 and Table 3). These high values reflect the relatively low productivity of the basin and the large reservoir of oxygenated water in the North Basin of the lake. An examination of the data presented in Figure 5 indicates that oxygen concentration and water temperature are inversely correlated, a reflection of the solubility of oxygen increasing as temperatures decline. As a result, there are significant differences in mean oxygen concentration among sample periods (Table 7).

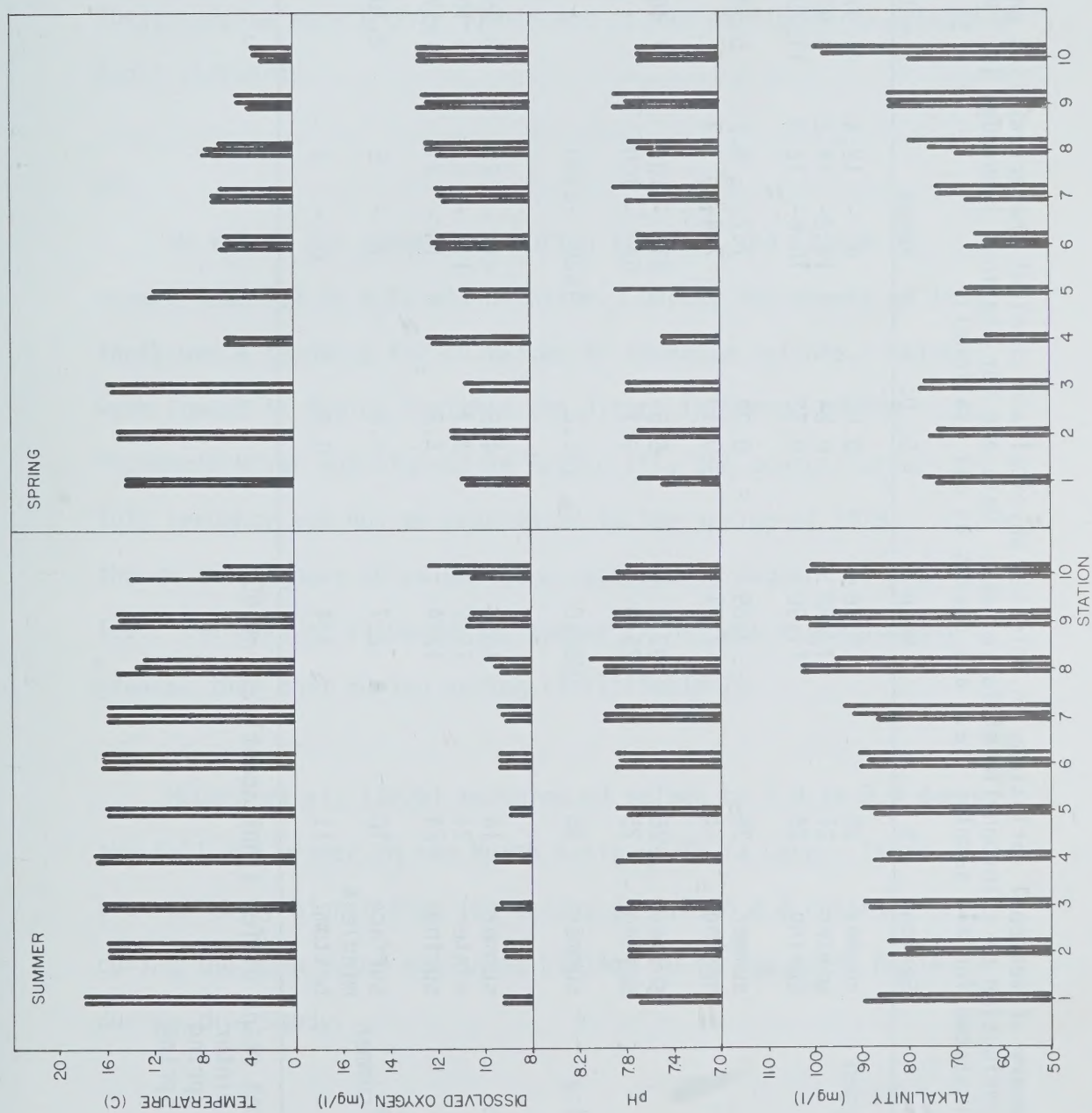


Figure 5. Temperature, dissolved oxygen, pH, and alkalinity for all stations and depths in Ya-Ya Lake during summer 1977 and spring 1978. Surface, midwater, and bottom samples are represented in order from left to right for each station.

Table 7. Summary of seasonal variations in selected physical and chemical characteristics and vertical distribution of chlorophylla of Ya-Ya lake. Data are for Stations 1 through 10. Means are calculated for all samples (ie. all depths at all stations).

Parameter	Season	n	Mean	S. D.	Range	T - test
Dissolved oxygen	summer	26	9.76	0.82	9 - 12.4	21.974* ¹
	winter	21	13.83	0.24	13.2- 14.2	9.873* ²
	spring	25	11.90	0.72	10.6- 12.8	11.791* ³
pH	summer	26	7.89	0.09	7.7- 8.1	5.544* ²
	spring	25	7.71	0.13	7.4- 7.9	
Alkalinity (mg/L)	summer	26	92.4	6.5	81 - 104	7.466* ²
	spring	25	75.9	9.1	64 - 100	
Reactive silica (µg/L)	summer	26	1860.0	135.2	1620 - 2280	
Total organic carbon(mg/L)	summer	14	10.0	4.5	<1 - 23	3.850* ¹
	winter	21	15.2	3.3	11 - 23	1.109* ²
	spring	24	12.4	7.2	1 - 31	1.590* ³
Chlorophyll a (µg/L)	summer	10	2.7	1.2	1 - 5	2.709*
	surface middle & bottom	11	1.4	0.8	0 - 2	

* indicates that means differ significantly. p < 0.05

¹ summer vs. winter

² summer vs. spring

³ winter vs. spring

There were a few instances in which supersaturation of oxygen is indicated. This probably reflects sampling error, particularly for those samples taken at stations within Region I. These samples were highly turbid and it was difficult to determine exact endpoints.

pH

pH values for summer and spring (Table 7 and Figure 5) ranged from 7.4 to 8.1, all alkaline. During the summer of 1977, there was a tendency for pH values to increase uplake. Values were lowest in Region I within the direct influence of the Mackenzie River and highest in Region III, the control area. This tendency was not as pronounced in the spring of 1978 though the highest pH values were recorded in Regions II and III. The mean pH value during summer (7.89) was significantly greater than that during spring (7.71)(Table 7).

McCart et al. (1976) measured pH values of 7.8 to 8.3 during the fall and winter in the North Basin of Ya-Ya Lake. These are slightly higher than the values of 7.7 to 8.0 recorded during the open water season at Station 10 in the North Basin during this study.

Alkalinity

Alkalinity values for summer and spring (Table 7 and Figure 5) ranged from 64 to 104 mg/L. The pattern of longitudinal

variation in alkalinity, within the summer and spring sampling periods, was very similar to that of pH with the greatest values being recorded in Region III, away from the influence of Mackenzie River water (Figure 5). The similarity of patterns for pH and alkalinity is not surprising in that alkalinity is a measure of the quantity and kinds of compounds which collectively shift pH to the alkaline side of neutrality (Wetzel, 1975).

The mean alkalinity for the summer period in 1977 (92.4 mg/L) was significantly greater than that for the spring of 1978 (75.9 mg/L)(Table 7).

Phosphorus

During summer 1977 and spring 1978, total phosphorus concentrations were positively correlated with suspended sediment concentrations ($r=0.77$, and 0.81 , respectively). As a result, during the summer and spring periods, concentrations were greatest in the most turbid areas of the lake in Region I, declined through Region II, and were lowest in Region III (Figure 6). During winter, when suspended sediment concentrations were probably relatively uniform throughout the lake, total phosphorus concentrations were as well, the only exception being an unusually high level recorded for the deep sample at Station 10 (Figure 6).

A comparison, among regions, of mean total phosphorus values for all samples taken in summer and spring (Table 6), indicates

that while total phosphorus concentrations did not differ between Regions II and III ($t=1.16$), both had significantly lower mean concentrations than Region I ($t=4.01$ and 8.22 , respectively). The regional differences in total phosphorus (TP) are almost entirely accounted for by the particulate phosphorus fraction since total dissolved phosphorus (TDP) concentrations were similar for all three regions (Figure 6). Overall, TDP concentrations averaged only 34% of TP concentrations during spring and summer and 69% during winter (based on those samples where both TDP and TP were above detection limits).

Total dissolved phosphorus concentrations averaged 13.4 ± 6.0 $\mu\text{g/L}$ (range <10 - 35 $\mu\text{g/L}$) for samples taken during the summer of 1977 and 11.8 ± 3.3 $\mu\text{g/L}$ (range <10 - 31 $\mu\text{g/L}$) for samples taken during the winter. The difference was not significant ($t=1.14$, $P>0.05$).

Where there were marked differences in either total phosphorus or total dissolved phosphorus with depth, the near-bottom samples generally had the highest values (Figure 6). Examples are the high total phosphorus concentrations in the winter bottom sample from Station 10 and the high total dissolved phosphorus concentrations in summer samples from Stations 6, 8, and 9 and winter samples from Stations 7, 8, and 10.

The concentrations of both total and total dissolved

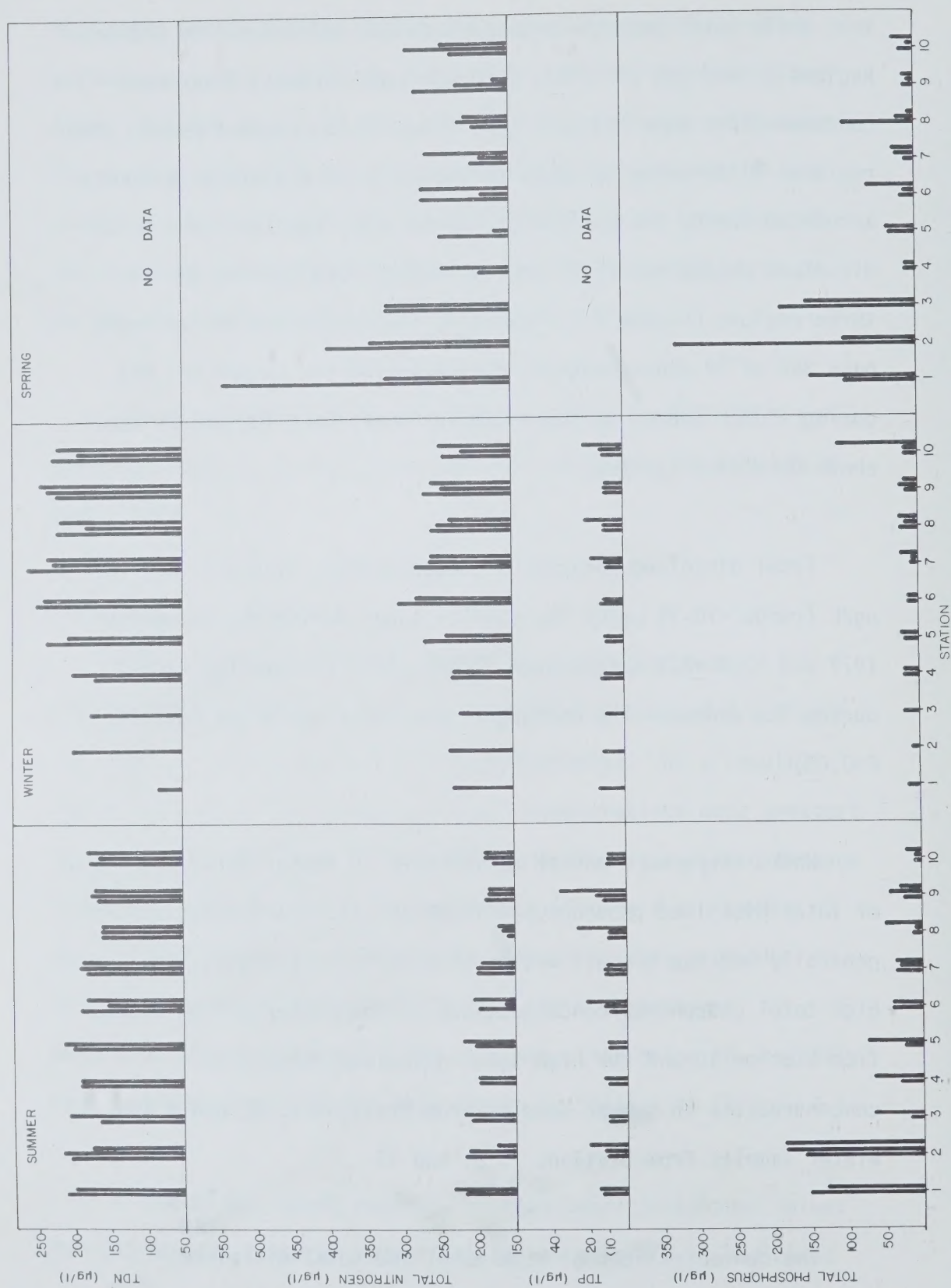


Figure 6. Concentrations of phosphorus and nitrogen, total and total dissolved (TD), for all stations and depths in Va-Va Lake during summer and winter 1977 and spring 1978. Surface, midwater, and

phosphorus in Ya-Ya Lake are relatively low and characteristic of Arctic lakes (Table 8). These low concentrations can have important consequences in limiting primary production in these lakes as phosphorus is commonly a limiting factor in aquatic ecosystems, the nutrient in shortest supply.

Nitrogen

Like total phosphorus, summer 1977 and spring 1978 total nitrogen concentrations were positively correlated with suspended sediment concentrations ($r=0.58$ and 0.71 , respectively). Concentrations tended, therefore, to be highest at stations in Region I and lowest at stations in Regions II and III (Figure 6). In contrast, in winter, when suspended sediment concentrations would be expected to be relatively uniform throughout the lake, total nitrogen concentrations were generally higher in Region II than in either Region I or Region III (Figure 6).

A comparison, among regions, of mean total nitrogen values for all samples taken during summer and spring (Table 6), indicates a pattern similar to that for total phosphorus. While total nitrogen concentrations did not differ between Regions II and III ($t=0.35$), both had significantly lower concentrations than Region I ($t=2.82$ and 4.13 , respectively). A comparison of total nitrogen (TN) with total dissolved nitrogen (TDN) values indicates that, in contrast with phosphorus, only a small proportion of the former is associated with the particulate fraction. Overall,

Table 8. Summary of macronutrient concentrations from other Arctic studies. Numbers represent mean $\pm$ S.E.
(range)

Region/Lakes	Time Period	No. of Lakes	TDN ($\mu\text{g/L}$)	TDP ($\mu\text{g/L}$)	SiO ₂ ($\mu\text{g/L}$)
TAGLU-RICHARDS ISLAND AND PARSONS LAKE AREA Upland	Aug.-Sept. 1975	13	(McCart et al., 1976) 279 $\pm$ 17.4 (176-358)	(<30-41)	354 $\pm$ 127 (110-1840)
	November 1975	13	421 $\pm$ 29.4 (268-624)	(<30)	400 $\pm$ 114 (80-1656)
	February 1976	13	664 $\pm$ 89.2 (260-1360)	(<30-31)	1160 $\pm$ 221 (360-2750)
	Aug.-Sept. 1975	7	203 $\pm$ 18.9 (168-294)	(<30-34)	1336 $\pm$ 222 (690-1900)
Floodplain	November 1975	7	306 $\pm$ 23.7 (228-430)	(<30)	1787 $\pm$ 288 (710-2590)
	February 1976	7	484 $\pm$ 71.9 (330-885)	(<30-50)	3166 $\pm$ 734 (1510-6600)
MACKENZIE VALLEY LAKES NEAR STUDY AREA (Brunskill et al., 1973)	Mar.-Nov. 1971-72	2	(574-644)	(12.7-18.3)	(168-216)
	Mar.-Nov. 1971-72	1	(26.6-336)	(5.3-25.7)	(2043-4568)
CHAR LAKE AND RESOLUTE LAKE ON CORNWALLIS ISLAND (Schindler et al., 1974)	Summer 1971	2	(65-146)	(1.0-44.0)	(219-330)
	May-June 1974	21	(83-392)	(2.0-61.0)	(99-1420)
STANWELL-FLETCHER LAKE (de March et al., 1977)	May-Sept. 1976	1	(82-154)	(0.7-1.9)	(209-250)

TDN values average approximately 94% of TN values during spring and summer and 84% during winter.

Total dissolved nitrogen concentrations averaged 183.0 ± 18.6 $\mu\text{g/L}$ (range 152-215 $\mu\text{g/L}$) during the summer of 1977 and 210.6 ± 38.8 $\mu\text{g/L}$ (range 80-258 $\mu\text{g/L}$) during the winter. This difference is significant ($t=3.21$, $P<0.05$).

The TDN values for Ya-Ya Lake fall within the range recorded for other Arctic lakes in the Northwest Territories (Table 8).

The December values for Station 10 (188 to 226 $\mu\text{g/L}$) are somewhat lower than those (216 to 280 $\mu\text{g/L}$) recorded by McCart et al. in the same area in November 1975 and February 1976.

Reactive Silica

Silica is an extremely important nutrient for the Bacillariophyta (diatoms), one of the dominant groups among the phytoplankton of Ya-Ya Lake, since it is a major constituent of their siliceous frustules. The concentrations recorded during this study (Figure 7 and Table 7) are generally lower than the fall and winter values (1620 to 2280 $\mu\text{g/L}$) reported by McCart et al. (1976) for the North Basin of Ya-Ya Lake but are within the range reported elsewhere for floodplain lakes in the Mackenzie Delta area. They are, however, higher than those reported for upland lakes in the northern Mackenzie Valley and lakes in the eastern Arctic (Table 8).

Total Organic Carbon

Concentrations of total organic carbon (TOC) ranged from less than 1 to 31 mg/L but there were no obvious patterns of variability in the lake (Figure 7). The mean concentration during winter (15.2 mg/L) exceeded that during summer (10.0 mg/L) and spring (12.4 mg/L) but only the difference between winter and summer was significant (Table 7).

Chlorophyll-a

Chlorophyll-a concentrations can be used as an indication of the relative productivity of lake waters. At Ya-Ya Lake, spring chlorophyll-a concentrations were below detection levels. No sampling was done during winter when phytoplankton populations were minimal. In summer (Figure 7), concentrations were highest in the surface waters at Station 1 and generally higher in Regions I and II, the more turbid areas of the lake, then in Region III, the least turbid area. At most stations, particularly those in Regions I and II, chlorophyll concentrations in surface waters were greater than those in bottom or midwater samples (Figure 7 and Table 7) where light levels are lower.

The Ya-Ya Lake values for summer, ranging from below detection to 5 mg/m³ and averaging 2.0 gm/m³ are slightly higher than several unpolluted Arctic lakes. Hobbie (1973) states "in arctic lakes concentrations of chlorophyll are always low." For example, Char Lake reached a peak concentration of 0.69 mg/m³

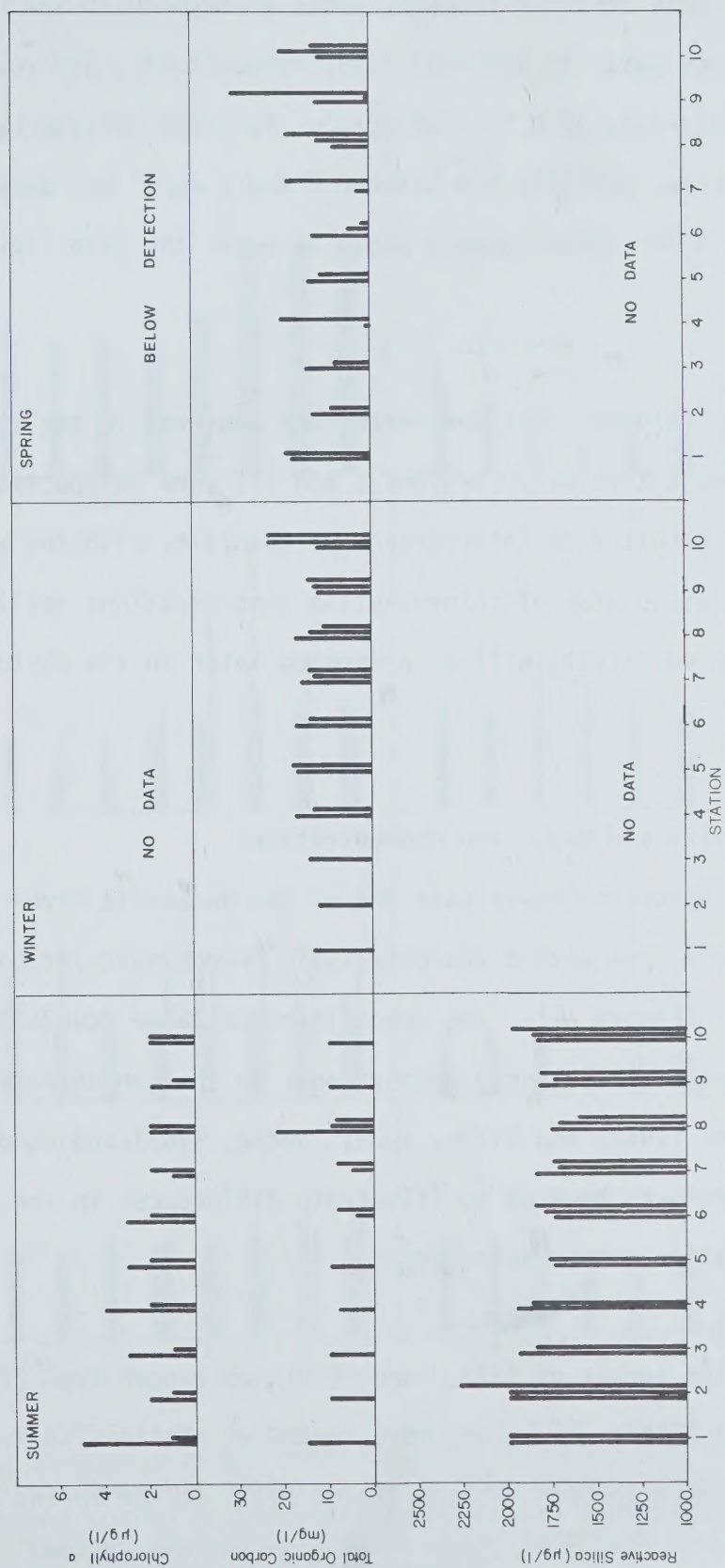


Figure 7. Reactive silica, total organic carbon, and chlorophyll-a concentration for all stations and depths in Ya-Ya Lake during summer and winter 1977 and spring 1978. Surface, midwater, and bottom samples are represented in order from left to right for each station.

in May. Lake Schrader (Hobbie, 1962) averaged 0.70 and 0.98 mg/m³ during open water in 1958 and 1959, respectively, and reached a peak in mid-July of 0.53-1.60 mg/m³. Polluted Meretta Lake, close to Char Lake, normally had between 3 and 5 mg/m³ but peaked at 24 mg/m³ after thawed sewage began to enter the lake (Kalff et al., 1972).

High chlorophyll-a concentrations measured in the regions with highest turbidity (Regions I and II) were unexpected. They probably result from interference of turbidity with the analytical method. Discussion of chlorophyll-a concentrations related to primary productivity will be presented later in the phytoplankton section.

Conductivity and Major Ion Concentrations

The waters of Ya-Ya Lake and of the Mackenzie River are of the bicarbonate type with a characteristic predominance of Ca and HCO₃ ions (Figure 8). The specific conductance (conductivity) of such waters is closely proportional to the concentrations of major ions (Juday and Birge, 1933; Rodhe, 1949) and conductivity can, therefore, be used to illustrate differences in ion concentration within waterbodies.

In the summer of 1977, conductivities ranged from 227 to 282 μ mhos (Table 9). They were lowest at stations in Region I and increased through Regions II and III. In the spring of 1978,

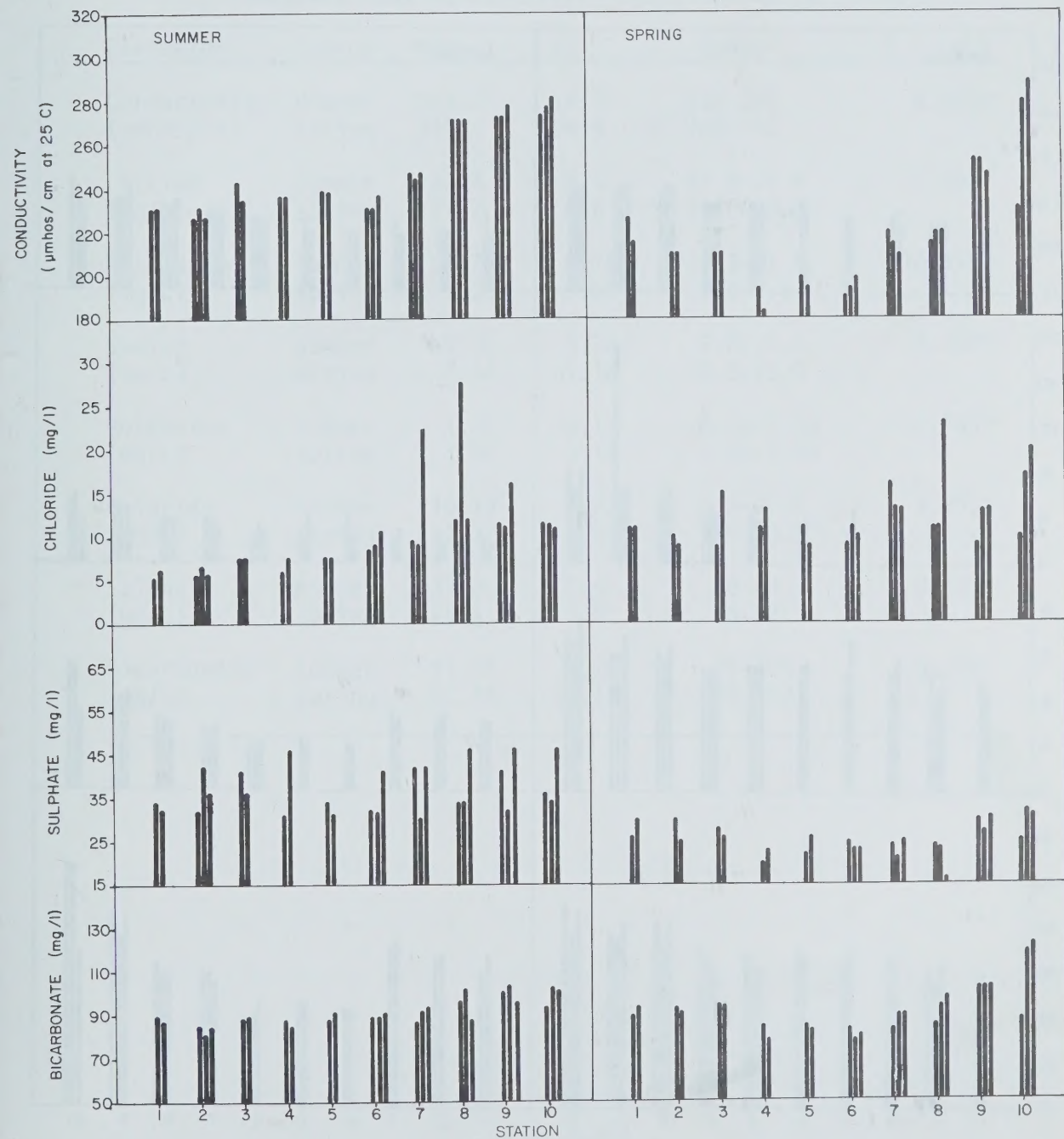


Figure 8. Conductivity and concentrations of major ions for all stations and depths in Ya-Ya Lake during summer 1977 and spring 1978. Surface, midwater, and bottom samples are represented in order from left to right for each station. (Continued).

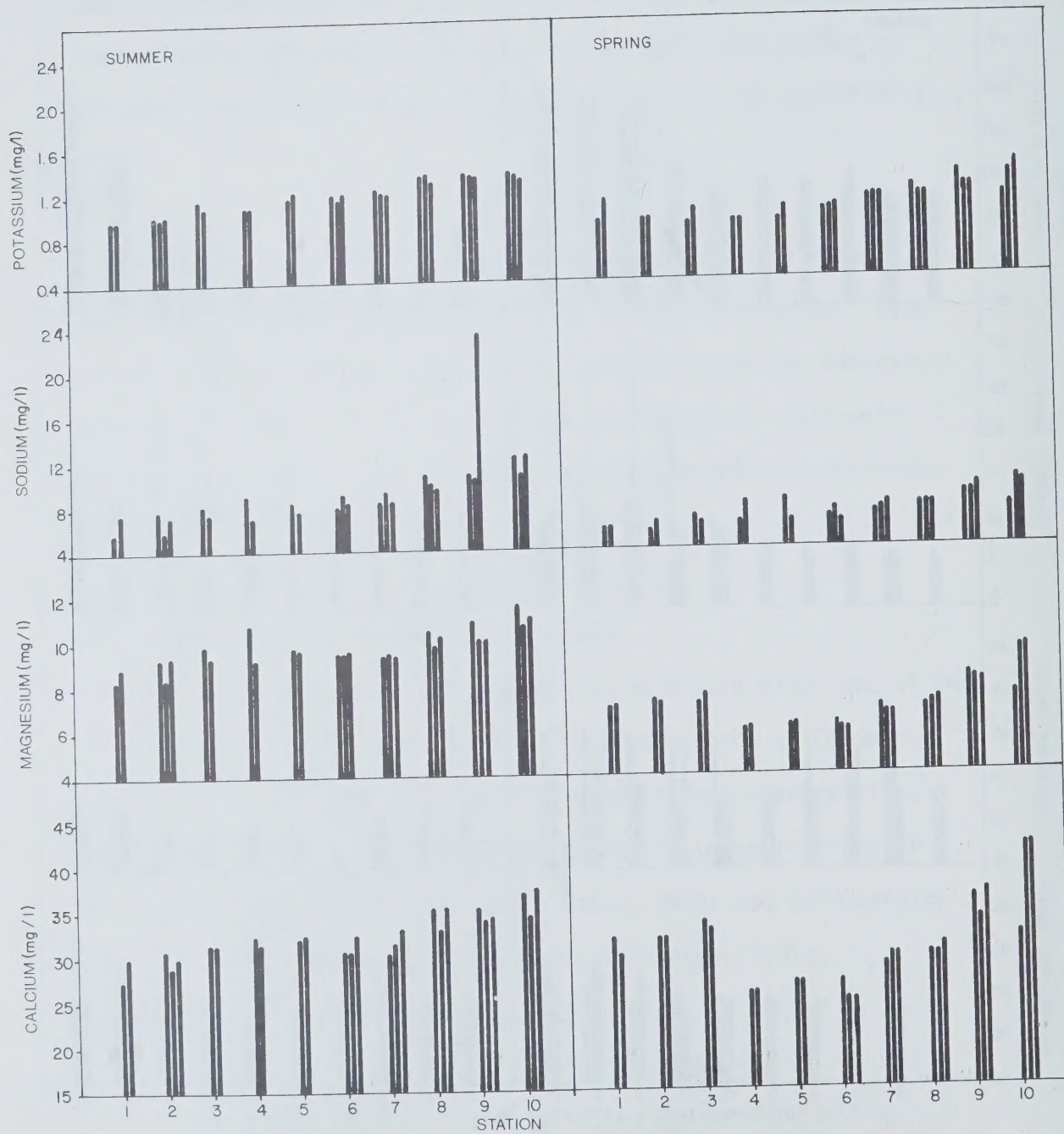


Figure 8. Concluded.

Table 9. A seasonal summary and comparison of conductivity and the major ions of Ya-Ya lake. Means are calculated from all sample depths at all stations. T - test comparisons are between summer and spring mean values and asterisks indicate that means differ significantly ($p < 0.05$).

Parameter	Season	Mean	SD	Range	T - test
Conductivity ($\mu\text{mhos/cm}$)	summer	249.6	19.7	227-282	4.575*
	spring	219.5	26.9	183-290	
Calcium (mg/L)	summer	32.4	2.5	27.6-37.6	1.208
	spring	31.2	4.6	25.0-42.0	
Magnesium (mg/L)	summer	9.79	0.78	8.3-11.6	10.470*
	spring	7.20	0.98	6.0-9.6	
Sodium (mg/L)	summer	9.34	3.32	5.8-23.3	3.582*
	spring	7.54	1.18	5.8-10.0	
Potassium (mg/L)	summer	1.17	0.13	0.96-1.34	2.743*
	spring	1.06	0.14	0.90-1.40	
Chloride (mg/L)	summer	10.19	5.07	5.5-27.5	1.731
	spring	12.32	3.54	9.0-23.0	
Sulphate (mg/L)	summer	37.0	5.5	30-46	8.752*
	spring	25.4	3.8	16-32	
Bicarbonate (mg/L)	summer	91.81	6.25	81-104	0.252
	spring	92.44	11.13	78-122	

conductivities ranged from 183 to 290 μmhos (Table 9). They were lowest at Station 4 and increased toward Station 1 and, to even higher levels, toward Station 10. These patterns presumably reflect the disposition of waters originating in the Mackenzie River, the predominant water in Region I, and those originating in the surrounding terrain, the predominant water in Region III. In both years, the pattern of variation in ionic concentrations indicated by conductivity values is reflected in the patterns for most of the individual ions (Figure 8). A comparison of the relative proportions of the major ions (Figure 9) at Stations 1 and 10, for the relatively stable summer period in 1977, indicates that water at the latter station has a greater representation of all of the major ions, particularly Na^+ and K^+ among the cations and Cl^- among the anions.

Mean conductivity was significantly greater during the summer of 1977 than during the spring of 1978 sampling period (Table 9). This seasonal difference in conductivity was reflected in differences in the concentrations of the magnesium, sodium, potassium, and sulphate ions but not in the concentrations of the calcium and bicarbonate, the predominant ions, or in the concentration of chloride ion (Table 9).

No data are available describing either conductivity or the concentrations of major ions in winter during the study period. McCart et al. (1976) found, however, that in the North Basin of

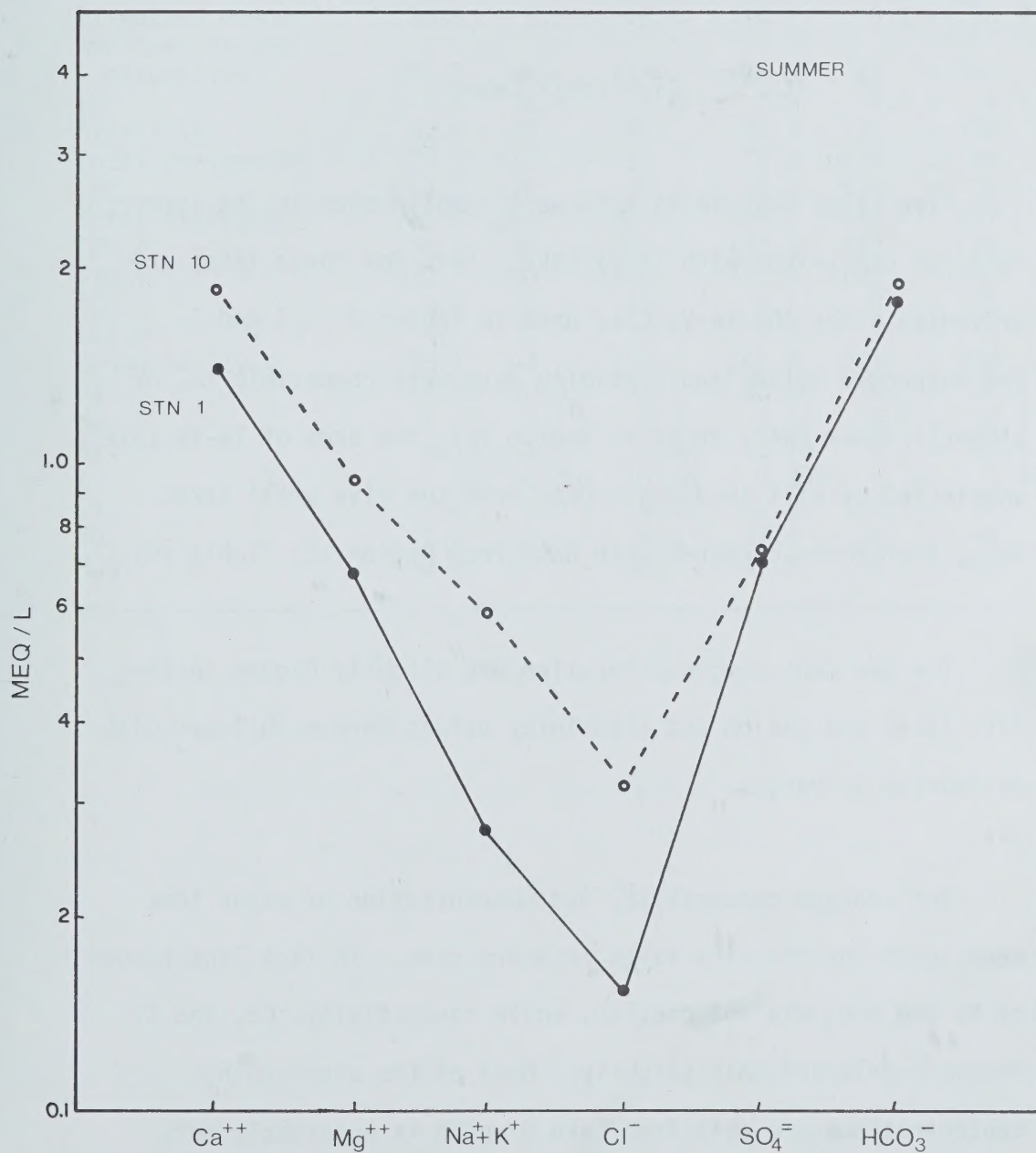


Figure 9. Relative values (milli-equivalents per litre, meq/L) for major ions in surface waters of Stations 1 and 10 from Ya-Ya Lake during summer 1977.

Ya-Ya Lake, in the vicinity of Station 10, conductivities increased from mid September (266 μmhos) to late February (315 to 335 μmhos). Such increases are common in lakes subject to extensive ice formation and are presumed to be the result of the freeze-out of salts during ice formation.

Five Small Lakes

Five lakes near Ya-Ya Lake were sampled once in the summer of 1977 for comparison with Ya-Ya Lake. Data for these lakes are presented after the Ya-Ya Lake data in Tables 3 , 4 and 5. The suspended solids and turbidity data were comparable to, or slightly lower than, those at Region III, the area of Ya-Ya Lake unaffected by silt loadings. Data from the five small lakes were, therefore, compared with data from Region III (Table 10).

The per cent oxygen saturation was slightly higher in the five lakes and the pH and alkalinity values were much lower with no overlap in ranges.

The average conductivity and concentration of major ions were lower for the five lakes in every case. In fact, the ranges of Na and HCO_3 did not overlap, while conductivity, Ca, and Cl ranges overlapped only slightly. Most of the overlapping concentrations are data from Lake C which is apparently more like Ya-Ya Lake than the others.

Table 10. Comparison between the summer water quality of Region III of Ya-Ya lake and 5 small nearby lakes. Means are calculated from all sample depths.

Parameter	Lakes A-E		Ya-Ya Lake Region III	
	Mean	Range	Mean	Range
Suspended solids	2.23	0.3 - 4.6	3.00	0.3 - 10.6
Turbidity-shaken	2.9	1.2 - 7.1	3.7	0.5 - 11.0
-settled	1.9	0.8 - 4.4	2.3	0.3 - 5.7
Dissolved oxygen	10.5	8.5 - 12.2	10.1	9.2 - 12.4
Per cent oxygen saturation	107.7	94 - 117	98.0	92 - 108
pH	7.2	6.9 - 7.4	7.9	7.8 - 8.1
Alkalinity	52.6	33 - 85	96.3	87 - 104
Total phosphorus	27.0	<10 - 53	28.2	<10 - 49
TDP	14.0	<10 - 23.0	14.3	<10 - 35
Total nitrogen	316.6	204 - 572	184.5	160 - 207
TDN	238.4	26 - 460	172.5	152 - 190
SiO ₂	812	360 - 1700	1792.0	1620 - 1980
TOC	8.6	5 - 12	9.7	4 - 23
Chl a	4	2 - 8	1.9	1 - 3
Conductivity	163.1	94 - 236	260.9	231 - 282
Ca	19.91	10.6 - 31.1	33.66	30.3 - 37.6
Mg	7.27	4.7 - 9.7	9.53	8.1 - 10.9
Na	6.14	4.9 - 7.4	10.78	8.1 - 23.3
K	1.061	0.80 - 1.28	1.254	1.12 - 1.34
Cl	8.0	6.0 - 9.5	12.8	8.5 - 27.5
SO ₄	17.7	<1 - 55.0	37.8	30 - 46
HCO ₃	52.6	33 - 85	95.2	87 - 104

The ranges of nutrient data for the five small lakes all overlap the ranges for Ya-Ya Lake Region III and the phosphorus and TOC concentrations are comparable. The nitrogen and chlorophyll-a concentrations are higher in the five small lakes, especially in Lake D, and the SiO_2 concentrations are generally lower, with Lake C having more comparable concentrations.

In summary, the five small lakes in the area near Ya-Ya Lake have levels of suspended solids quite comparable to the region of Ya-Ya Lake unaffected by silt loading. In general, however, all of the small lakes except Lake C are very different from Ya-Ya Lake with respect to water quality.

Conclusions

1. Ya-Ya Lake can be divided into three regions on the basis of suspended sediments and turbidity. Regions I (Stations 1-3), II (Stations 4-5), and III (Stations 6-10) can be regarded as areas of maximum, moderate, and non-impact, respectively, in terms of the negative effects of siltation.

2. The suspended sediment concentrations, using combined summer and spring data, differ significantly between regions, averaging 119.9, 17.6, and 5.1 gm/L for Regions I, II, and III, respectively.

3. There is a curvilinear relationship between Secchi values and suspended sediment concentrations similar to that found by McCart et al. (1976).

4. Values for shaken turbidity and suspended sediments are highly correlated for samples from both the summer of 1977 and the spring of 1978.

5. The settled turbidity constituted only a small proportion of the shaken turbidity within Region I and this proportion increased uplake. The currents detectable in Region I throughout the open water season probably kept settleable sediments in suspension.

6. The North Basin of Ya-Ya Lake was thermally stratified in the summer of 1977. The shallower, more exposed South Basin did not stratify during the study period. In general, higher water temperatures were recorded in summer and spring near the outlet of the lake.

7. Dissolved oxygen concentrations were high throughout the lake during each of the sampling periods, never falling below 9 mg/L and 89% saturation.

8. pH values for summer and spring ranged from 7.4 to 8.1, all on the alkaline side. There was a tendency for pH values

to increase uptake.

9. Alkalinity values for summer and spring ranged from 64 to 104 mg/L and followed a similar pattern of longitudinal variation to pH.

10. Total phosphorus and total nitrogen were both positively correlated with suspended sediment concentrations, and concentrations were greatest in the most turbid areas of the lake in Region I. The regional differences in total phosphorus are almost entirely accounted for by the particulate phosphorus fraction. In contrast, the total dissolved nitrogen fraction accounted for the major portion of the total nitrogen.

11. Summer reactive silica concentrations ranged from 1620 to 2280 $\mu\text{g/L}$.

12. Concentrations of total organic carbon ranged from less than 1 to 31 mg/L.

13. Chlorophyll-a concentrations in surface waters were greater than those in bottom or midwater samples where light levels are lower. Summer values averaged $2.0 \mu\text{g/m}^3$, slightly higher than several unpolluted Arctic lakes.

14. The waters of Ya-Ya Lake are of the bicarbonate type

with a characteristic predominance of Ca and HCO_3 ions.

15. The regional pattern of conductivity differed between summer and spring reflecting the disposition of waters originating in the Mackenzie River in Region I and those originating in the surrounding terrain in Region III.

16. In general, all of the small lakes except Lake C are very different from Ya-Ya Lake with respect to water quality.

PHYTOPLANKTON

By

R. Green, B.Sc.

PHYTOPLANKTON

Introduction

Until recently, little was known of the phytoplankton community associated with Arctic lakes. Investigations by Coulon et al. (1972), Hobbie et al. (1973), Kalff and Welch (1974), McCart et al. (1976), Moore (1978), and Sheath et al. (1975a, 1978) have done much to supply baseline information regarding taxonomy and distribution of the phytoplankton. Examinations of the primary productivity of phytoplankton in the Arctic environment have been undertaken by many, including Frey and Stahl (1958), Goldman (1960), Hobbie (1964), Kalff (1967), Howard and Prescott (1971), O'Brien et al. (1975), and Sheath et al. (1975b).

The aim of the present study is to examine and determine the effects of an increased turbidity load on the primary production and other aspects of the phytoplankton community of Ya-Ya Lake. The effects of turbidity on the phytoplankton of Arctic lakes has been little studied. Until the present study, only Oliver (1964), Coulon et al. (1972), Hobbie (1964), and Hobbie et al. (1973) had examined highly turbid Arctic lakes.

Methods

Population Studies

Field Methods

Samples of phytoplankton were taken with a Kemmerer water sample bottle. Those taken from Ya-Ya Lake and the five unnamed lakes during the open water season were from a depth of approximately 0.5 m below the water surface. Those taken from Ya-Ya Lake during December, 1977, were from immediately below the ice. Samples associated with the primary production studies were taken at depths coinciding with the water sampling and incubation depths described below. All samples intended for phytoplankton population studies were transferred to 125 ml amber glass bottles and preserved with Lugol's solution.

Laboratory Analysis

The phytoplankton samples were examined according to the technique of Utermohl (1958). Thoroughly agitated subsamples, 0.5-25 ml in volume were allowed to settle in settling chambers at a rate of 3 h per cm of settling chamber height. Counts and identifications were made using a Wild M40 inverted microscope equipped with phase contrast illumination. Magnifications of 750x were used for enumeration, and up to 1875x for identification.

Cell numbers were converted to volumes (Table 11) by using the average dimensions of each phytoplankton species and

Table 11. Algal species recorded from Ya-Ya Lake and the 5 unnamed lakes during August, 1977 to July, 1978. Also given are calculated volumes (μm^3) for each species present.

Species	Volume μm^3 /single cell	Ya Ya Lake		
		Region I	Region II	Region III
Chlorophyta				
<i>Ankistrodesmus convolutus</i> Corda	150			
<i>Ankistrodesmus flaccatus</i> (Corda) Ralfs	260	+		+
(syn. <i>Monoraphidium setiforme</i>)	250			
<i>Carteria klebsii</i> (Dang.) Dill	200	+	+	+
<i>Chlamydomonas</i> spp.	250			
<i>Cosmarium bioculatum</i> Brebisson	25			
<i>Crucigenia crucifera</i> (Wolle) Collins	20			+
<i>Crucigenia quadrata</i> Morren	25			
<i>Crucigenia tetrapedia</i> (Kirch.) West & West	120			
<i>Franceia ovalis</i> (France) Lemmermann	80	+		
<i>Lagerheimia quadriseta</i> (Lemm.) G. M. Smith	120			
<i>Lagerheimia subsala</i>	86	+		+
<i>Monoraphidium arcuatum</i> Hindak	750			+
<i>Oocystis Borgei</i> Snow	80			
<i>Oocystis parva</i> West & West	100			
<i>Pediastrum Boryanum</i> (Turp.) Bory.	100			
<i>Pediastrum duplex</i> Meyer	200			
<i>Quadrigula lacustris</i> (Chod.) G.M. Smith	60			+
<i>Scenedesmus bijuga</i> (Turp.) Lemmermann	120			
<i>Scenedesmus lefevrii</i> Deflandre	250			
<i>Schroederia setigera</i> (Schroed.) Lemmermann	150		+	+
<i>Tetraedron minimum</i> (A. Braun) Hansgîrg	180			
<i>Tetraedron muticum</i> (A. Braun) Hansgîrg				

Cyanophyta

Anabaena spp

30

(Continued)

Table 11. Continued.

Species	Volume μm^3 /single cell	Ya Ya Lake		
		Region I	Region II	Region III
<i>Chroococcus dispersus</i> (v. Keiss) Lemmermann	10			
<i>Coelosphaerium Kuetszingianum</i> Naegeli	20			
<i>Lyngbya limnetica</i> Kutzing	10			
Xanthophyta				
<i>Ophiocytium parvulum</i> (Perty) A. Braun	400			
Chrysophyta				
<i>Aulomonas purdyi</i> Lackey	60			
<i>Amphimonas</i> sp. (?)	100	+	+	+
<i>Bicoeca parva</i> Hilliard	120			
<i>Bicoeca</i> spp.	200			
<i>Bitrichia chodatii</i> (Reverdin.) Chodat	150			+
<i>Chromulina</i> spp.	35	+	+	+
<i>Chrysococcus rufescens</i> Klebs	35	+		
<i>Chrysochromulina parva</i> Lackey	20	+	+	+
<i>Chrysoikos skujae</i> (Nauerck) Willen	50	+		+
<i>Chrysolykos planktonicus</i> Mack	35			+
<i>Dinobryon attenuatum</i> (Hilliard) Hilliard	300		+	+
<i>Dinobryon bavaricum</i> Imhof.	600			
<i>Dinobryon borgei</i> Lemmermann	120		+	+
<i>Dinobryon campulostipatum</i> Ahlstrom	300			+
<i>Dinobryon crenulatum</i> Wm. and G.S. West	400			+
<i>Dinobryon cylindricum</i> Imhof.	400	+	+	+
<i>Dinobryon divergens</i> Imhof.	600	+		+
<i>Dinobryon sertularia</i> Ehrenberg	500			+
<i>Dinobryon sociale</i> Ehrenberg	600	+	+	+
<i>Dinobryon suecicum</i> var. <i>longispinum</i> Lemmermann	175			
<i>Dinobryon</i> spp.	400		+	+

(Continued)

Table 11. Continued.

Species	Volume μm^3 /single cell	Ya Ya Lake		
		Region I	Region II	Region III
<i>Epipyxis alaskarum</i> Hilliard	80			+
<i>Kephyrion obliquum</i> Hilliard	30			+
<i>Kephyrion</i> spp.	30	+	+	+
<i>Kephyriopsis</i> spp.	30			+
<i>Mallomonas akrokomos</i> Ruttner	150			+
<i>Mallomonas</i> spp.	380		+	+
<i>Monosiga varians</i> var. <i>vagens</i> Skuja	25			+
<i>Ochromonas</i> spp.	35	+	+	+
<i>Pseudokephyrion alaskarum</i> Hilliard	50			+
<i>Pseudokephyrion inflatum</i> Hilliard	60		+	+
<i>Pseudokephyrion pseudospinale</i> Bourrelly	30			+
<i>Pseudokephyrion undulatifissimum</i> Scherffel	50			
<i>Pseudokephyrion</i> spp.	60		+	+
<i>Pseudokephyrion</i> spp.	275	+	+	+
<i>Salpingoeca frequentissima</i> (Zach.) Lemmermann	70			
<i>Spiniferomonas bilacunosa</i> Takahashi	100		+	+
<i>Spiniferomonas bournellii</i> Takahashi	100			+
<i>Spiniferomonas</i> spp.	100			+
<i>Steleomonas dichotoma</i> Lackey	80	+	+	
<i>Synerypta</i> sp.	225			
<i>Uroglena volvox</i> Ehrenberg	80			
<i>Uroglenopsis americana</i> (Calkins) Lemmermann	80			+
Unidentified spp.	20			+
Bacillariophyta				
<i>Achnanthes exigua</i> Grunow	150		+	
<i>Achnanthes lemmermanni</i> Hustedt	350			+

(Continued)

Table 11. Continued.

Species	Volume μm^3 /single cell	Ya Ya Lake		
		Region I	Region II	Region III
<i>Achnanthes lanceolata</i> (Brebisson) Grunow	350			+
<i>Achnanthes minutissima</i> (Kutz.) Grunow	190			+
<i>Achnanthes</i> spp.	150	+		+
<i>Amphora coffeiformis</i> (Ag.) Kutzing	1200			+
<i>Amphora ovalis</i> var. <i>pediculus</i> Kutzing	920			+
<i>Asterionella formosa</i> Hassal.	360	+	+	+
<i>Cocconeis placentula</i> var. <i>lineata</i> (Ehr.) V.H.	7500			
<i>Cocconeis</i> spp.	2500			+
<i>Cyclotella comta</i> (Ehrenberg) Kutzing	1800	+		+
<i>Cyclotella comta</i> var. <i>oligactis</i> (Ehr.) Grunow	240	+		+
<i>Cyclotella meneghiniana</i> Kutzing	300			+
<i>Cyclotella ocellata</i> Pantocsek	240			+
<i>Cyclotella atomus</i> Hustedt	84			+
<i>Cyclotella stelligera</i> Cleve and Grunow	80		+	
<i>Cyclotella glomerata</i> Bachmann	240		+	
<i>Gymbella minuta</i> Hilse ex Rabh.	885	+		+
<i>Gymbella minuta</i> f. <i>latens</i> (Krasske) Reimer	885	+		+
<i>Diatoma tenue</i> Agardh.	200			
<i>Diatoma tenue</i> var. <i>elongatum</i> Lyngbya	280		+	+
<i>Fragilaria pinnata</i> Ehrenberg	70		+	+
<i>Fragilaria</i> spp.	200			+
<i>Gomphonema</i> spp.	400			
<i>Melosira varians</i> Agardh.	325		+	
<i>Navicula pupula</i> var. <i>rectangularis</i> (Greg.) Grun.	1000	+		

(Continued.)

Table 11. Continued.

Species	Volume μm^3 /single cell	Ya Ya Lake		
		Region I	Region II	Region III
<i>Navicula tuscula</i> (Ehrenberg) Grunow	4500			+
<i>Navicula</i> spp.	360	+		+
<i>Nitzschia acicularis</i> (Kutzing) Wm. Smith	110	+	+	+
<i>Nitzschia palea</i> (Kutzing) Wm. Smith	560			
<i>Nitzschia palea</i> (Kutzing) Wm. Smith	1800	+		
<i>Nitzschia vermicularis</i> (Kutzing) Wm. Smith	400	+		
<i>Nitzschia</i> spp.	4000			+
<i>Pinnularia</i> spp.	90	+	+	+
<i>Rhizosolenia eriensis</i> H.L. Smith	100	+	+	+
<i>Stephanodiscus hantzschia</i> Grunow	2135			+
<i>Stephanodiscus astrea</i> var. <i>minutula</i> (Kutz) Grun.	100			+
<i>Stephanodiscus</i> spp.	5652			+
<i>Surirella angustata</i> Kutzing	1460	+		
<i>Surirella</i> sp.	1200		+	+
<i>Synedra acus</i> Kutzing				
<i>Synedra acus</i> var. <i>radians</i> (Kutz.) Husted	800			
<i>Synedra delicatissima</i> Wm. Smith	1400		+	
<i>Synedra</i> spp.	1250	+	+	+
<i>Tabellaria fenestrata</i> (Lyngbya) Kutzing	4600	+		
Cryptophyta				
<i>Cryptomonas marsonii</i> Skuja	750			+
<i>Cryptomonas ovata</i> Ehrenberg	1250			
<i>Cryptomonas</i> spp.	1000	+	+	+
<i>Rhodomonas minuta</i> Skuja	180	+		
Pyrrophyta				
<i>Gymnodinium</i> spp.	16000			+
(Continued)				

Table 11. Continued.

Species	Volume $\mu\text{m}^3/\text{single cell}$	Ya Ya Lake		
		Region I	Region II	Region III
<i>Peridinium inconspicuum</i> Lemmermann	800			+
<i>Peridinium</i> spp.	1750			+
Euglenophyta				
<i>Euglena polymorpha</i> Dangeard	8010			
<i>Trachelomonas</i> sp.	3220			

Table 11. Continued.

Species	Volume μm^3 single cell	Unnamed Lakes			
		A	B	C	D
Chlorophyta					
<i>Ankistrodesmus convolutus</i> Corda	150				
<i>Ankistrodesmus flaccatus</i> (Corda) Ralfs (syn. <i>Monoraphidium setiforme</i>)	260		+		
<i>Carteria lkebsii</i> (Dang.) Dill	250				+
<i>Chlamydomonas</i> spp.	200	+	+		+
<i>Cosmarium bioculatum</i> Brebisson	250	+			+
<i>Crucigenia crucifera</i> (Wolle) Collins	25			+	
<i>Crucigenia quadrata</i> Morren	20				
<i>Crucigenia tetrapedia</i> (Kirch.) West & West	25	+	+		+
<i>Franceia ovalis</i> (France) Lemmermann	120	+	+		
<i>Lagerheimia quadriseta</i> (Lemm.) G.M. Smith	80		+		
<i>Lagerheimia subsala</i>	120				
<i>Monoraphidium arcuatum</i> Hindak	86				
<i>Oocystis Borgei</i> Snow	750	+			
<i>Oocystis parva</i> West & West	80	+			+
<i>Pediastrum Boryanum</i> (Turp.) Bory.	100				+
<i>Pediastrum duplex</i> Meyen	100				+
<i>Quadrigula lacustris</i> (Chod.) G.M. Smith	200		+		+
<i>Scenedesmus bijuga</i> (Turp.) Lemmermann	60	+			+
<i>Scenedesmus lefevrii</i> Deflandre	120				+
<i>Schroederia setigera</i> (Schroed.) Lemmerman	250				
<i>Tetraedron minimum</i> (A. Braun) Hansgirg	150	+	+	+	+
<i>Tetraedron muticum</i> (A. Braun) Hansgirg	180				
Cyanophyta					
<i>Anabaena</i> spp.	30		+		+

(Continued)

Table 11. Continued.

Species	Volume μm^3 / single cell	A	B	Unnamed Lakes		
				C	D	E
<i>Chroococcus dispersus</i> (v. Keiss) Lemmermann	10				+	
<i>Coelosphaerium Kuetsingianum</i> Naegeli	20	+				
<i>Lyngbya limnetica</i> Kutzing	10		+			
Xanthophyta						
<i>Ophiocytium parvulum</i> (Perty) A. Braun	400		+			
Chrysophyta						
<i>Aulomonas purdyi</i> Lackey	60					+
<i>Amphimonas</i> sp. (?)	100				+	
<i>Bicoeca parva</i> Hilliard	120			+		
<i>Bicoeca</i> spp.	200					
<i>Bitrichia chodatii</i> (Reverdin.) Chodat	150	+	+	+		+
<i>Chromulina</i> spp.	35					
<i>Chrysococcus rufescens</i> Klebs	35					
<i>Chrysochromulina parva</i> Lackey	20	+	+	+		+
<i>Chrysoikos skujae</i> (Nauerck) Willen	50					
<i>Chrysolykos planktonicus</i> Mack	35					
<i>Dinobryon attenuatum</i> (Hilliard) Hilliard	300			+		
<i>Dinobryon bavaricum</i> Imhof.	600		+			
<i>Dinobryon borgei</i> Lemmermann	120		+	+		+
<i>Dinobryon campanulostipatum</i> Ahlstrom	300					
<i>Dinobryon crenulatum</i> Wm. and G.S. West	400	+	+			+
<i>Dinobryon cylindricum</i> Imhof.	400	+				
<i>Dinobryon divergens</i> Imhof.	600					
<i>Dinobryon sertularia</i> Ehrenberg	500					
<i>Dinobryon sociale</i> Ehrenberg	600	+	+			
<i>Dinobryon suecicum</i> var. <i>longispinum</i> Lemmermann	175	+				+
<i>Dinobryon</i> spp.	400			+		

(Continued)

Table 11. Continued.

Species	Volume μm^3 / single cell	Unnamed Lakes				
		A	B	C	D	E
<i>Epiplatys alaskarum</i> Hilliard	80		+			
<i>Kephyrion obliquum</i> Hilliard	30					
<i>Kephyrion</i> spp.	30	+				
<i>Kephyriopsis</i> spp.	30					
<i>Mallomonas akrokomos</i> Ruttner	150			+	+	
<i>Mallomonas</i> spp.	380				+	
<i>Monosiga varians</i> var. <i>vagens</i> Skuja	25	+	+		+	+
<i>Ochromonas</i> spp.	35		+	+	+	+
<i>Pseudokephyrion alaskarum</i> Hilliard	50					
<i>Pseudokephyrion inflatum</i> Hilliard	60					
<i>Pseudokephyrion pseudospinale</i> Bourrelly	30				+	
<i>Pseudokephyrion undulatisimum</i> Scherffel	50					+
<i>Pseudokephyrion</i> spp.	60					+
<i>Pseudopedinella erkensis</i> Skuja	275	+	+	+		+
<i>Salpingoeca frequentissima</i> (Zach.) Lemmermann	70					
<i>Spiniferomonas bilacunosa</i> Takahashi	100					
<i>Spiniferomonas bourrellii</i> Takahashi	100		+	+		
<i>Spiniferomonas</i> spp.	100					
<i>Stelomonas dichotoma</i> Lackey	80					
<i>Synarypta</i> sp.	225		+			
<i>Uroglena volvox</i> Ehrenberg	80	+		+		
<i>Uroglenopsis americana</i> (Calkins) Lemmermann	80					
Unidentified spp.	20	+			+	
<i>Bacillariophyta</i>						
<i>Achnanthes exigua</i> Grunow	150					
<i>Achnanthes lemmermanni</i> Hustedt	350					

(Continued)

Table 11. Continued.

Species	Volume μm^3 / single cell	Unnamed Lakes				
		A	B	C	D	E
<i>Achnanthes lanceolata</i> (Brebisson) Grunow	350					
<i>Achnanthes minutissima</i> (Kutz.) Grunow	190		+			
<i>Achnanthes</i> spp.	150				+	
<i>Amphora coffeiformis</i> (Ag.) Kutzing	1200					
<i>Amphora ovalis</i> var. <i>pediculus</i> Kutzing	920					
<i>Asterionella formosa</i> Hassal.	360		+			
<i>Cocconeis placentula</i> var. <i>lineata</i> (Ehr.) V.H.	7500					
<i>Cocconeis</i> spp.	2500					
<i>Cyclotella comta</i> (Ehrenberg) Kutzing	1800					
<i>Cyclotella comta</i> var. <i>oligactis</i> (Ehr.) Grunow	240					
<i>Cyclotella meneghiniana</i> Kutzing	300					
<i>Cyclotella ocellata</i> Pantocsek	240					
<i>Cyclotella atomus</i> Hustedt	84					
<i>Cyclotella stelligera</i> Cleve and Grunow	80					
<i>Cyclotella glomerata</i> Bachmann	240	+	+	+	+	+
<i>Cymbella minuta</i> Hilse ex Rabh.	885					
<i>Cymbella minuta</i> f. <i>latens</i> (Krasske) Reimer	885					
<i>Diatoma tenue</i> Agardh	200					
<i>Diatoma tenue</i> var. <i>elongatum</i> Lyngbya	280		+			
<i>Fragilaria pinnata</i> Ehrenberg	70					
<i>Fragilaria</i> spp.	200					
<i>Gomphonema</i> spp.	400					
<i>Melosira varians</i> Agardh.	325					
<i>Navicula pupula</i> var. <i>rectangularis</i> (Greg.) Grun.	1000				+	

(Continued.)

Table 11. Continued.

Species	Volume μm^3 / single cell	Unnamed Lakes				
		A	B	C	D	E
<i>Peridinium inconspicuum</i> Lemmermann	800	+				
<i>Peridinium</i> spp.	1700		+			+
Euglenophyta						
<i>Euglena polymorpha</i> Dangeard	8010		+			
<i>Trachelomonas</i> sp.	3220		+			

calculating cell volumes according to the method of Findenegg (1969). The resulting cell volumes were then converted to biomass values assuming a specific gravity of 1.

Identifications were based on Bourrelly (1968, 1970), Croasdale (1973), Hilliard (1966, 1967), Lowe (1975), Patrick and Reimer (1966, 1975), Prescott (1962), Sreenivasa and Duthie (1975), Skuja (1948, 1964), Tiffany and Britton (1952), Whitford and Schumacher (1973), and Willen (1963).

Methods of calculating dominance indices for major groups of phytoplankton are those of Ulfstrand (1968).

Shannon-Weaver species diversity indices (Shannon and Weaver, 1949) were computed for all phytoplankton samples from Ya-Ya Lake and the unnamed lakes by the machine formula of Lloyd et al. (1968). This formula is:

$$\bar{d} = \frac{C}{N} (N \log_{10} N - \sum n_i \log_{10} n_i)$$

where: $C = 3.32193$

N = total number of individuals

n_i = total number of individuals in the i^{th} species (form)

Species diversity is dependent on the number of species (richness) and the distribution of individuals among the species

(evenness). Shannon and Weaver's theoretical measure of mean species diversity per individual ($\bar{d}$) is sensitive to, and increases with, both species richness and evenness. The value of $\bar{d}$ is proportional to the uncertainty of identification of an individual selected at random from a multi-species population. In general, $\bar{d}$ values range from zero to any positive number, but are seldom greater than 10. The $\bar{d}$ value is at a minimum when all individuals belong to the same species, whereas $\bar{d}$ is at a maximum value when each species contains the same number of individuals. In this study, each obtained $\bar{d}$ value was compared with a hypothetical maximum based on MacArthur's broken stick model (MacArthur, 1957) of natural populations (population with a few relatively abundant species and increasing numbers of species with only a few individuals). Such a comparison results in an index termed "equitability" or "e" by Lloyd and Ghelardi (1964). Equitability values were computed using the Table of Lloyd and Ghelardi (1964) in conjunction with the following formula:

$$\bar{d} = \frac{S'}{S}$$

where: S = number of species (forms) in the sample

S' = the tabulated number of species for MacArthur's model
of equal diversity

Values of "e" range from 0 to 1. Environmental Protection Agency biologists in the U.S. have found the equitability index to be

very sensitive to even slight levels of environmental degradation (United States Environmental Protection Agency, 1973).

Primary Production

Field Methods

The basic technique used in determining primary productivity was the ^{14}C method of Steeman-Nielsen (1952). Primary production was determined separately at Stations 2 (very turbid), 6 (moderately turbid), and 8 (clear). At each station, water samples were taken at several depths depending in part on Secchi disk transparency and in part on maximum depth. Samples were taken at two depths at Station 2 (0 and 0.5 m), three depths at Station 6 (0.5, 1.5, 2.5 m), and four depths at Station 8 (1.0, 2.0, 3.0, and 4.0 m).

One light and one dark calibrated bottle, each containing 125 ml of sample, were inoculated with 1 ml of 4 μC of ^{14}C as NaHCO_3 . The sample bottles were suspended at their respective collection depths and incubated for a 3-4 h period during the morning. The experiments were run on separate days for each station: August 3, 1977, for Station 8; August 4 for Station 2; and August 5 for Station 6. After the incubation period, the samples were placed in a light-free box and transported back to the campsite where they were filtered through a 35 mm diameter Sartorius membrane filter of 0.2 μm pore size. Filters were air dried and sent to the International ^{14}C Agency, Denmark, for counting.

Insolation in the study area was recorded throughout the study period with a Belmont Recording Pyrheliometer (Model 53850). Light penetration into the water was measured, during each experiment, with an underwater photometer (Selenium photocell). Secchi disc visibility was measured at the time of incubation with a 20 cm diameter black and white disc.

Laboratory Analysis

The total inorganic carbon available for photosynthesis was calculated from the total alkalinity (Hach Kit method), pH (Radio-meter pH Meter, Type 296), conductivity (Beckman Solu-bridge RB4-250), and water temperature (mercury thermometer) by means of a nomograph prepared by Bachmann (Saunders et al., 1962).

Rates of carbon fixation (as $\text{mg C m}^{-2} \text{ d}^{-1}$) were calculated from pyrheliometer readings and data supplied by the International ^{14}C Agency, Denmark, using the methods of Anderson (1974).

Results and Discussion

Population Studies

The data on which the presentation in this section is based are included in Tables 12 through 14.

During the study, a total of 123 species was identified from Ya-Ya Lake and the five smaller lakes: 92 from Ya-Ya Lake itself,

Table 12. Total density (total density as cells/mL) and total biomass (as mg/m³) of the phytoplankton from 6 sites on the south basin of Ya-Ya lake during August and December, 1977 and July 1978. Also given are the number of species, diversity index (d'), equitability value (e) and the relative abundance of the major groups based upon the total density and the total biomass.

Site Depth (m) Date	1						2					
	0.5	0.5	12/12/77	07/07/78	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	03/08/77	12/12/77	12/12/77	07/07/78	04/08/77	03/08/77	12/12/77	03/08/77	12/12/77	07/07/78	07/07/78	07/07/78
Chlorophyta												
<i>Chlamydomonas</i> spp.												142
<i>Crucigenia quadrata</i>												
<i>Lagerheimia quadriseta</i>												
<i>Monoraphidium arcuatum</i>												36
<i>Monoraphidium setiforme</i>												
<i>Tetraedron minimum</i>												71
Chrysophyta												
<i>Aulomonas purdyi</i>												
<i>Chromulina</i> spp.												71
<i>Chrysococcus rufescens</i>												142
<i>Chrysochromulina parva</i>												
<i>Chrysolykos planctonicus</i>												
<i>Chrysoikos skujae</i>												
<i>Dinobryon borgei</i>												
<i>Dinobryon attenuatum</i>												
<i>Dinobryon cylindricum</i>												
<i>Dinobryon divergens</i>												
<i>Dinobryon sociale</i>												
<i>Kephyrion</i> spp.												
<i>Mallomonas</i> sp.												
<i>Monosiga varians</i> var. <i>vagans</i>												36
<i>Ochromonas</i> spp.												

(Continued)

Table 12. Continued.

Site Depth (m) Date	1			2		
	0.5 03/08/77	0.5 12/12/77	0.5 07/07/78	0.5 04/08/77	0.5 03/08/77	0.5 12/12/77
<i>Pseudokephyrion alaskanum</i>						
<i>Pseudokephyrion inflatum</i>						
<i>Pseudokephyrion</i> spp.						
<i>Pseudopedinella erkinsis</i>						
<i>Spiniferomonas bilacunosa</i>						
<i>Spiniferomonas bourrellii</i>						
<i>Steleomonas dichotoma</i>				41		18
Bacillariophyta						
<i>Achnanthes exigua</i>						
<i>Achnanthes</i> spp.				71		
<i>Asterionella formosa</i>			36			
<i>Cocconeis placentula</i> var. <i>lineata</i>						
<i>Cyclotella comta</i>						
<i>Cyclotella comta</i> var. <i>oligactis</i>	142					
<i>Cyclotella meneghiniana</i>						
<i>Cyclotella stelligera</i>						
<i>Cyclotella glomerata</i>						
<i>Cymbella minuta</i>	142	53	107	284	71	18
<i>Diatoma tenue</i>						
<i>Diatoma tenue</i> var. <i>elongatum</i>						
<i>Gomphonema</i> spp.						
<i>Melosira varians</i>						
<i>Navicula</i> spp.						
(Continued)						18

36

Table 12. Continued.

Site Depth (m) Date	1				2			
	0.5 03/08/77	0.5 12/12/77	0.5 07/07/78	0.5 04/08/77	0.5 03/08/77	0.5 12/12/77	0.5 07/07/78	
<i>Nitzschia acicularis</i>			36					36
<i>Nitzschia vermicularis</i>					142			
<i>Nitzschia</i> spp.								
<i>Rhizosolenia eriensis</i>								
<i>Stephanodiscus astrea</i> var. <i>minutula</i>								
<i>Stephanodiscus hantzschia</i>								
<i>Surirella angustata</i>								
<i>Surirella</i> spp.				71				
<i>Synedra acus</i>								
<i>Synedra delicatissima</i>								
<i>Synedra</i> spp.								
<i>Tabellaria fenestrata</i>								
Pyrrophyta								
<i>Gynodinium</i> spp.								
Cryptophyta								
<i>Cryptomonas marsonii</i>								
<i>Cryptomonas</i> spp.								
<i>Rhodomonas minuta</i>								213
Total cells/mL	426.0	53.0	358.0	852.0	284.0	54.0	357.0	
Total biomass mg/m ³	99.4	12.7	76.6	224.8	98.7	12.2	101.1	
Number of species	3	1	6	8	3	3	5	
$\bar{d}$	1.10	-	1.48	1.91	1.04	-	1.23	
e	1.0	-	0.60	0.63	0.66	-	0.60	

(Continued)

Table 12. Continued.

Site Depth (m) Date	1				2			
	0.5 03/08/77	0.5 12/12/77	0.5 07/07/78	0.5 04/08/77	0.5 03/08/77	0.5 12/12/77	0.5 07/07/78	0.5
Per cent composition of major groups based upon total density and total biomass:								
Chlorophyta								
% total cells/mL	33.3 (142)	-	-	8.3 (71)	25.0 (71)	-	-	10.1 (36)
% biomass mg/m ³	28.6 (28.4)	-	-	8.2 (18.5)	25.2 (24.9)	-	-	5.3 (5.4)
Chrysophyta								
% total cells/mL	-	-	20.1 (72)	33.3 (284)	-	33.3 (18)	-	10.1 (36)
% biomass mg/m ³	-	-	19.2 (14.7)	4.9 (11.0)	-	11.8 (1.4)	-	21.4 (21.6)
Bacillariophyta								
% total cells/mL	66.7 (284)	100.0 (53)	50.0 (179)	50.0 (426)	75.0 (213)	66.7 (36)	-	20.2 (72)
% biomass mg/m ³	71.4 (71.0)	100.0 (12.7)	55.7 (42.6)	81.2 (182.5)	74.8 (73.8)	88.2 (10.8)	-	35.4 (35.8)
Pyrrophyta								
% total cells/mL	-	-	-	-	-	-	-	-
% biomass mg/m ³	-	-	-	-	-	-	-	-
Cryptophyta								
% total cells/mL	-	-	29.9 (107)	8.3 (71)	-	-	-	59.2 (213)
% biomass mg/m ³	-	-	25.2 (19.3)	5.7 (12.8)	-	-	-	37.9 (38.3)

(Continued)

Table 12. Continued.

Site Depth (m) Date	3			4			5	
	0.5 02/08/77	0.5 11/12/77	0.5 07/07/78	0.5 03/08/77	0.5 08/12/77	0.5 06/07/78	0.5 02/08/77	0.5 02/08/77
Chlorophyta								
<i>Chlamydomonas</i> spp.	85					71		213
<i>Crucigenia quadrata</i>								
<i>Lagerheimia quadriseta</i>	14		36					
<i>Monoraphidium arcuatum</i>								
<i>Monoraphidium setiforme</i>								
<i>Tetraedron minimum</i>						7		
Chrysophyta								
<i>Automonas purdyi</i>	43			71				
<i>Chromulina</i> spp.	28							
<i>Chrysococcus rufescens</i>								
<i>Chrysochromulina parva</i>						142		71
<i>Chrysolykos planctonicus</i>	156							
<i>Chrysoikos skujae</i>								
<i>Dinobryon borgei</i>				36		21		36
<i>Dinobryon attenuatum</i>						7		
<i>Dinobryon cylindricum</i>						43		
<i>Dinobryon divergens</i>								
<i>Dinobryon sociale</i>	99			142		43		
<i>Kephyrion</i> spp.	28			36				
<i>Mallomonas</i> sp.								
<i>Monosiga varians</i> var. <i>vagans</i>						14		
<i>Ochromonas</i> spp.	46					7		249

(Continued)

Table 12. Continued.

Site Depth (m) Date	3			4			5
	0.5 02/08/77	0.5 11/12/77	0.5 07/07/78	0.5 03/08/77	0.5 08/12/77	0.5 06/07/78	0.5 02/08/77
<i>Pseudokephyron alaskanum</i>							
<i>Pseudokephyron inflatum</i>						14	
<i>Pseudokephyron</i> spp.						14	
<i>Pseudopedinella erkinsis</i>	14		36			50	
<i>Spiniferomonas bilacunosa</i>						14	
<i>Spiniferomonas bourrellii</i>							
<i>Stelezomonas dichotoma</i>				36			
Bacillariophyta							
<i>Achnanthes exigua</i>					18		
<i>Achnanthes</i> spp.							
<i>Asterionella formosa</i>							213
<i>Cocconeis placentula</i> var. <i>lineata</i>							
<i>Cyclotella comta</i>	28						
<i>Cyclotella comta</i> var. <i>oligactis</i>							
<i>Cyclotella meneghiniana</i>							
<i>Cyclotella stelligera</i>				284			
<i>Cyclotella glomerata</i>			107	107		21	36
<i>Cymbella minuta</i>	426						
<i>Diatoma tenue</i>							
<i>Diatoma tenue</i> var. <i>elongatum</i>							
<i>Gomphonema</i> spp.							
<i>Melosira varians</i>			71				
<i>Navicula</i> spp.			36				

(Continued)

Table 12. Continued.

Site Depth (m) Date	3			4			5	
	0.5 02/08/77	0.5 11/12/77	0.5 07/07/78	0.5 03/08/77	0.5 08/12/77	0.5 05/07/78	0.5 02/08/77	0.5 02/08/77
<i>Nitzschia acicularis</i>	71			249				
<i>Nitzschia vermicularis</i>			36					
<i>Nitzschia</i> spp.			71					
<i>Rhizosolenia eriensis</i>	14			36				
<i>Stephanodiscus astrea</i> var. <i>minutula</i>						21		
<i>Stephanodiscus hantzschia</i>								
<i>Surirella angustata</i>								
<i>Surirella</i> spp.								
<i>Synedra acus</i>					18			
<i>Synedra delicatissima</i>		18						
<i>Synedra</i> spp.			36					
<i>Tabellaria fenestrata</i>								
Pyrrophyta								
<i>Gynodinium</i> spp.								
Cryptophyta								
<i>Cryptomonas marsonii</i>	43					7		
<i>Cryptomonas</i> spp.	497		142			462	178	
<i>Rhodomonas minuta</i>								
Total cells/mL	1592.0	18.0	571.0	997.0	54.0	972.0	996.0	
Total biomass mg/m ³	384.7	22.5	313.4	184.7	35.1	185.7	136.1	
Number of species	15	1	9	9	3	19	7	
$\bar{d}$	2.08	-	2.05	1.89	-	1.96	1.74	
e	0.40	-	0.67	0.56	-	0.26	0.57	

(Continued)

Table 12. Continued.

Site Depth (m) Date	3			4			5
	0.5 02/08/77	0.5 11/12/77	0.5 07/07/78	0.5 03/08/77	0.5 08/12/77	0.5 06/07/78	0.5 02/08/77
Per cent composition of major groups based upon total density and total biomass:							
Chlorophyta							
% total cells/mL	6.2 (99)	-	6.3 (36)	-	-	8.0 (78)	21.4 (213)
% biomass mg/m ³	4.8 (18.1)	-	0.9 (2.9)	-	-	8.2 (15.3)	3.1 (4.3)
Chrysophyta							
% total cells/mL	26.0 (41.4)	-	6.3 (36)	32.2 (321)	-	39.4 (383)	35.7 (356)
% biomass mg/m ³	18.8 (72.4)	-	3.2 (9.9)	52.9 (97.7)	-	40.3 (74.9)	10.6 (14.5)
Bacillariophyta							
% total cells/mL	33.9 (539)	100.0 (18)	62.5 (357)	67.8 (676)	100.0 (54)	4.3 (42)	25.0 (249)
% biomass mg/m ³	42.0 (161.7)	100.0 (22.5)	87.8 (275.0)	47.1 (81.0)	100.0 (35.1)	3.8 (7.1)	62.7 (85.3)
Pyrrophyta							
% total cells/mL	-	-	-	-	-	-	-
% biomass mg/m ³	-	-	-	-	-	-	-
Cryptophyta							
% total cells/mL	33.9 (540)	-	24.9 (142)	-	-	48.3 (469)	17.9 (178)
% biomass mg/m ³	34.4 (132.5)	-	8.2 (25.6)	-	-	47.6 (88.4)	23.6 (32.0)

(Continued)

Table 12. Continued.

Site Depth (m) Date	5		6					
	0.5 10/12/77	0.5 08/07/78	0.5 31/07/77	0.5 04/08/77	0.5 04/08/77	0.5 10/12/77	0.5 06/07/78	
Chlorophyta								
<i>Chlamydomonas</i> spp.		36	170	36	57		170	
<i>Crucigenia quadrata</i>			57					
<i>Lagerheimia quadriseta</i>								
<i>Monoraphidium arcuatum</i>			71	36				
<i>Monoraphidium setiforme</i>								
<i>Tetraedron minimum</i>								
Chrysophyta								
<i>Aulomonas purdyi</i>	36		28	36	14		156	
<i>Chromulina</i> spp.	36				14			
<i>Chrysococcus rufescens</i>								
<i>Chrysochromulina parva</i>	36		57	107	14		426	
<i>Chrysolykos planctonicus</i>			14					
<i>Chrysoikos skujae</i>			14					
<i>Dinobryon borgei</i>	71		170	71	57			
<i>Dinobryon attenuatum</i>								
<i>Dinobryon cylindricum</i>								
<i>Dinobryon divergens</i>								
<i>Dinobryon sociale</i>	142		241	142	142		256	
<i>Kephyrion</i> spp.	36		43	71	28		14	
<i>Mallomonas</i> sp.							28	
<i>Monosiga varians</i> var. <i>vagans</i>			71	142	86	35	14	
<i>Ochromonas</i> spp.							14	

(Continued)

Table 12. Continued.

Site Depth (m) Date	5		6				
	0.5 10/12/77	0.5 08/07/78	0.5 31/07/77	0.5 04/08/77	0.5 04/08/77	0.5 10/12/77	0.5 06/07/78
<i>Pseudokephyrion alaskanum</i>				36			
<i>Pseudokephyrion inflatum</i>					14		114
<i>Pseudokephyrion</i> spp.		36		36	412		
<i>Pseudopedinella erkinsis</i>		36					
<i>Spiniferomonas bilacunosa</i>			57	36			43
<i>Spiniferomonas bourrellii</i>			28	107	43		
<i>Steleoromonas dichotoma</i>							
Bacillariophyta							
<i>Achnanthes exigua</i>							
<i>Achnanthes</i> spp.					57		
<i>Asterionella formosa</i>							
<i>Cocconeis placentula</i>					28		
var. <i>lineata</i>							
<i>Cyclotella comta</i>							
<i>Cyclotella comta</i> var. <i>oligactis</i>							14
<i>Cyclotella meneghiniana</i>			14				
<i>Cyclotella stelligera</i>							
<i>Cyclotella glomerata</i>							
<i>Cymbella minuta</i>	18	320	113	426	213		57
<i>Diatoma tenue</i>	18						
<i>Diatoma tenue</i> var. <i>elongatum</i>		2201					
		36					
<i>Gomphonema</i> spp.							
<i>Melosira varians</i>							
<i>Navicula</i> spp.							18

(Continued)

Table 12. Continued.

Site	5		6			
	0.5	0.5	0.5	0.5	0.5	0.5
Depth (m)	10/12/77	08/07/78	31/07/77	04/08/77	10/12/77	06/07/78
Date						
<i>Nitzschia acicularis</i>			14			
<i>Nitzschia vermicularis</i>						
<i>Nitzschia</i> spp.			14	36		
<i>Rhizosolenia eriensis</i>						
<i>Stephanodiscus astrea</i>					18	
var. <i>minutula</i>						
<i>Stephanodiscus hantzschia</i>						
<i>Surirella angustata</i>						14
<i>Surirella</i> spp.						
<i>Synedra acus</i>		36				
<i>Synedra delicatissima</i>		36				
<i>Synedra</i> spp.						
<i>Tabellaria fenestrata</i>						
Pyrrophyta						
<i>Gyrodinium</i> spp.						14
Cryptophyta						
<i>Cryptomonas marsonii</i>				14		28
<i>Cryptomonas</i> spp.		568	327	284	312	951
<i>Rhodomonas minuta</i>						
Total cells/mL	36.0	3662.0	1503.0	1638.0	1505.0	2313.0
Total biomass mg/m ³	7.9	1023.3	327.8	321.8	358.0	2753.0
Number of species	2	15	19	16	16	16
d	-	1.46	2.44	2.38	2.18	1.90
e	-	0.20	0.37	0.44	0.38	0.31

(Continued)

Table 12. Continued.

Site Depth (m) Date	5			6		
	0.5 10/12/77	0.5 08/07/78	0.5 31/07/77	0.5 04/08/77	0.5 04/08/77	0.5 10/12/77
Per cent composition of major groups based upon total density and total biomass:						
Chlorophyta						
% total cells/mL	-	1.0 (36)	19.8 (298)	4.4 (72)	3.8 (57)	7.3 (170)
% biomass mg/m ³	-	0.7 (7.2)	16.4 (53.6)	5.1 (16.6)	0.3 (1.1)	1.2 (34.0)
Chrysophyta						
% total cells/mL	-	11.7 (429)	48.1 (723)	47.9 (784)	54.8 (824)	49.3 (35)
% biomass mg/m ³	-	10.8 (111.0)	55.3 (181.2)	35.0 (112.6)	60.1 (215.1)	2.7 (1.2)
Bacillariophyta						
% total cells/mL	100.0 (36)	71.8 (2629)	10.3 (155)	28.2 (462)	19.7 (298)	50.7 (36)
% biomass mg/m ³	100.0 (7.9)	78.5 (802.9)	10.4 (34.1)	32.8 (105.5)	20.0 (71.6)	97.3 (44.2)
Pyrrophyta						
% total cells/mL	-	-	-	-	-	0.6 (14)
% biomass mg/m ³	-	-	-	-	-	81.4 (2240.0)
Cryptophyta						
% total cells/mL	-	15.5 (568)	21.8 (327)	19.5 (320)	21.7 (326)	-
% biomass mg/m ³	-	10.0 (102.2)	18.0 (58.9)	27.1 (87.1)	19.6 (70.2)	-
						7.0 (192.2)

Table 13. Total density (as cells/mL) and total biomass (as mg/m³) of the phytoplankton from stations 7 - 10 on the north basin of Ya-Ya lake during August and December, 1977 and July, 1978. Also given are the number of species, diversity index ($\bar{d}$), equitability value (e), and the relative abundance of the major groups based upon total density and total biomass.

Station Depth (m) Date	7			8		
	0.5 03/07/77	0.5 09/12/77	0.5 06/07/78	0.5 03/08/77	1.0 03/08/77	2.0 03/08/77
Chlorophyta						
<i>Carteria klebsii</i>						
<i>Chlamydomonas</i> spp.	107	7	42	107	11	
<i>Oocystis Borgei</i>				28		
<i>Oocystis parva</i>			3			
<i>Monoraphidium arcuatum</i>						
<i>Quadrigula lacustris</i>			3		3	8
<i>Tetraedron minimum</i>						
Chrysophyta						
<i>Aulomonas purdyi</i>						3
<i>Bitrichia chodatii</i>					8	11
<i>Chromulina</i> spp.	213		73	21		59
<i>Chrysochromulina parva</i>	355		342	355	22	8
<i>Chrysolykos planctonicus</i>	36		6	14	8	
<i>Chrysoikos skujae</i>	36		3	7		
<i>Dinobryon attenuatum</i>						
<i>Dinobryon borgei</i>	213			71	20	8
<i>Dinobryon campulostipitum</i>						3
<i>Dinobryon crenulatum</i>				7	8	14
<i>Dinobryon cylindricum</i>					6	
<i>Dinobryon divergens</i>						
<i>Dinobryon sertularia</i>	36					
<i>Dinobryon sociale</i>	178		25	263	216	255

(Continued)

Table 13. Continued.

Station Depth (m) Date	7			8		
	0.5 30/07/77	0.5 09/12/77	0.5 06/07/78	0.5 03/08/77	1.0 03/08/77	2.0 03/08/77
<i>Dinobryon</i> spp.				7		
<i>Kephyrion obliquum</i>						
<i>Kephyrion</i> spp.	142		31	71	8	11
<i>Kephyriopsis</i> spp.					6	11
<i>Mallomonas akrokomos</i>						
<i>Mallomonas</i> spp.						
<i>Monosiga varians</i> var. <i>vagans</i>	71 107					
<i>Ochromonas</i> spp.			14	28		
<i>Pseudokephyrion inflatum</i>			3			
<i>Pseudokephyrion pseudospirale</i>				7		6
<i>Pseudokephyrion</i> spp.			70	21	3	
<i>Pseudopedinella erkinsis</i>	36		34		3	1
<i>Salpingoeca frequentissima</i>						
<i>Spiniferomonas bourrellii</i>	36		3			
<i>Spiniferomonas</i> spp.				4		
<i>Stelaxomonas dichotoma</i>				7		6
<i>Uroglenopsis americana</i>						
Unidentified chrysophyceae	36					
Bacillariophyta						
<i>Achnanthes lemmermannii</i>					6	
<i>Achnanthes lanceolata</i>						3
<i>Achnanthes minutissima</i>					8	
<i>Achnanthes</i> spp.					14	
<i>Amphora coffeiformis</i>					3	
<i>Amphora ovalis</i> var. <i>pediculus</i>					3	
<i>Asterionella formosa</i>				14	20	

(Continued)

Table 13. Continued.

Station Depth (m) Date	7			8		
	0.5	0.5	0.5	0.5	1.0	2.0
	30/07/77	09/12/77	06/07/78	03/08/77	03/08/77	03/08/77
<i>Cocconeis placentula</i> var. <i>lineata</i>						
<i>Cocconeis</i> spp.			8			
<i>Cyclotella comta</i>						
<i>Cyclotella comta</i> var. <i>oligactis</i>	107		14			
<i>Cyclotella ocellata</i>						
<i>Cyclotella atomus</i>			11			
<i>Cyclotella glomerata</i>			81	291	655	607
<i>Cymbella minuta</i>						
<i>Cymbella minuta</i> f. <i>latens</i>					6	3
<i>Diatoma tenue</i>						
<i>Diatoma tenue</i> var. <i>elongatum</i>						
<i>Fragilaria pinnata</i>					3	
<i>Fragilaria</i> spp.						3
<i>Navicula tuscula</i>					14	
<i>Navicula</i> spp.				7		
<i>Nitzschia acicularis</i>					3	
<i>Pinnularia</i> spp.					3	6
<i>Rhizosolenia eriensis</i>						
<i>Stephanodiscus hantzschia</i>						
<i>Stephanodiscus</i> spp.						3
<i>Synedra acus</i>						
<i>Synedra</i> spp.	36					
Pyrrophyta						
<i>Peridinium inconspicuum</i>				7		

(Continued)

Table 13. Continued.

Station Depth (m) Date	7			8		
	0.5 30/07/77	0.5 09/12/77	0.5 06/07/78	0.5 03/08/77	1.0 03/08/77	2.0 03/08/77
<i>Peridinium</i> spp. <i>Gymnodinium</i> spp.						
Cryptophyta <i>Cryptomonas marsonii</i> <i>Cryptomonas</i> spp. <i>Rhodomonas minuta</i>	71	3 300	128			
Total cells/mL	1816.0	7.0	1069.0	1468.0	1060.0	1029.0
Total biomass mg/m ³	298.0	0.2	162.4	333.2	345.5	335.6
Number of Species	17	1	20	21	25	20
$\bar{d}$	2.55	-	2.03	2.23	1.45	1.34
e	0.47	-	0.25	0.28	0.12	0.15
Per cent composition of the major groups based upon the total density and total biomass.						
Chlorophyta total cell total cells/mL	5.9 (107)	100.0 (7)	4.5 (48)	9.2 (135)	1.3 (14)	0.8 (8)
% total biomass	7.2 (21.4)	100.0 (0.2)	5.7 (9.3)	12.7 (42.4)	2.6 (8.8)	0.4 (1.2)
Chrysophyta total cell/mL	82.3 (1495)	-	56.5 (604)	60.4 (886)	29.1 (308)	38.5 (396)

(Continued)

Table 13. Continued.

Station Depth (m) Date	7			8		
	0.5 30/07/77	0.5 09/12/77	0.5 06/07/78	0.5 03/08/77	1.0 03/08/77	2.0 03/08/77
Per cent composition of the major groups based upon the total density and total biomass.						
Chrysophyta % biomass mg/m ³	64.8 (193.1)	-	30.9 (50.4)	56.0 (186.6)	40.7 (140.6)	49.0 (164.4)
Bacillariophyta % total cells/mL	7.9 (143)	-	10.7 (114)	21.2 (312)	69.6 (738)	60.7 (625)
% biomass mg/m ³	23.7 (70.7)	-	28.5 (46.4)	22.7 (75.6)	56.7 (196.1)	50.6 (170.0)
Pyrrophyta % total cells/mL	-	-	-	0.5 (7)	-	-
% biomass mg/m ³	-	-	-	1.7 (5.6)	-	-
Cryptophyta % total cells/mL	3.9 (71)	-	28.3 (303)	8.7 (128)	-	-
% biomass mg/m ³	4.3 (12.8)	-	34.8 (56.3)	6.9 (23.0)	-	-

(Continued)

Table 13. Continued.

Station Depth (m) Date	8				9		
	3.0 03/08/77	4.0 03/08/77	0.5 09/12/77	0.5 09/07/78	0.5 31/07/77	0.5 08/12/77	
Chlorophyta							
<i>Carteria klebsii</i>							
<i>Chlamydomonas</i> spp.		22		45	76		
<i>Oocystis Borgei</i>	19	6					
<i>Oocystis parva</i>					11		
<i>Monoraphidium arcuatum</i>	14	3		6	8		
<i>Quadrifigula lacustris</i>					25		
<i>Tetraedron minimum</i>	14	6		6			
Chrysophyta							
<i>Aulomonas purdyii</i>				3			
<i>Bitrichia chodatii</i>	5				3		
<i>Chromulina</i> spp.		22		67	31		
<i>Chrysochromulina parva</i>	19	28		22	638		
<i>Chrysolykos planctonicus</i>	14	6			17		
<i>Chrysoikos skujae</i>				3			
<i>Dinobryon attenuatum</i>		3					18
<i>Dinobryon borgei</i>	5	20			6		
<i>Dinobryon campanulostipitum</i>							
<i>Dinobryon crenulatum</i>	5	6			6		
<i>Dinobryon cylindricum</i>		3		11			
<i>Dinobryon divergens</i>		3					
<i>Dinobryon sertularia</i>							
<i>Dinobryon sociale</i>	156	104		11	39		

(Continued)

Table 13. Continued.

Station Depth (m) Date	8			9		
	3.0 03/08/77	4.0 03/08/77	0.5 09/12/77	0.5 09/07/78	0.5 31/07/77	0.5 08/12/77
<i>Dinobryon</i> spp.	5					
<i>Kephyrion obliquum</i>		3				
<i>Kephyrion</i> spp.	38	6	18	17	20	
<i>Kephyriopsis</i> spp.						
<i>Mallomonas akrokomos</i>				6		
<i>Mallomonas</i> spp.						
<i>Monosiga varians</i> var.						
<i>vagans</i>						
<i>Ochromonas</i> spp.		3		39	28	
<i>Pseudokephyrion inflatum</i>	8			8	3	
<i>Pseudokephyrion pseudospirale</i>						
<i>Pseudokephyrion</i> spp.	24	6		70	6	
<i>Pseudopedinella erakensis</i>		17		42	3	
<i>Salpingoeca frequentissima</i>						
<i>Spiniferomonas bourrellii</i>				6	3	
<i>Spiniferomonas</i> spp.						
<i>Stelexomonas dichotoma</i>	5					
<i>Uroglenopsis americana</i>						
Bacillariophyta						
<i>Achnanthes lemmermannii</i>						
<i>Achnanthes lanceolata</i>						
<i>Achnanthes minutissima</i>						
<i>Achnanthes</i> spp.						
<i>Amphora coffeiformis</i>						
<i>Amphora ovalis</i> var.						
<i>pediculus</i>						
<i>Asterionella formosa</i>						

(Continued)

Table 13. Continued.

Station Depth (m) Date	8			9		
	3.0 03/08/77	4.0 03/08/77	0.5 09/12/77	0.5 09/07/78	0.5 31/07/77	0.5 08/12/77
<i>Cocconeis placentula</i> var. <i>lineata</i>						18
<i>Cocconeis</i> spp.						
<i>Cyclotella comta</i>						
<i>Cyclotella comta</i> var. <i>oligactis</i>				6		
<i>Cyclotella ocellata</i>					112	
<i>Cyclotella atomus</i>						
<i>Cyclotella glomerata</i>				179	700	
<i>Cymbella minuta</i>	596	834			3	
<i>Cymbella minuta</i> f. <i>latens</i>			18			
<i>Diatoma tenue</i>						
<i>Diatoma tenue</i> var. <i>elongatum</i>					8	
<i>Fragilaria pinnata</i>					3	
<i>Fragilaria</i> spp.						
<i>Navicula tuseula</i>						
<i>Navicula</i> spp.		6		6	3	18
<i>Nitzschia acicularis</i>			18			
<i>Pinnularia</i> spp.						
<i>Rhizosolenia eriensis</i>	5					
<i>Stephanodiscus hantzschia</i>					140	
<i>Stephanodiscus</i> spp.				11		
<i>Synedra acus</i>						
<i>Synedra</i> spp.		3				
<i>Pyrrophyta</i>						
<i>Peridinium inconspicuum</i>					3	

(Continued)

Table 13. Continued.

Station Depth (m) Date	8				9			
	3.0 03/08/77	4.0 03/08/77	0.5 09/12/77	0.5 09/07/78	0.5 31/07/77	0.5 08/12/77		
Per cent composition of the major groups based upon the total density and total biomass.								
Chrysophyta % biomass mg/m ³	38.7 (103.3)	24.8 (78.4)	2.7 (0.5)	19.9 (36.2)	15.4 (44.1)	9.5 (5.4)		
Bacillariophyta % total cells/mL	64.5 (601)	64.1 (852)	66.7 (36)	26.0 (202)	51.0 (969)	66.7 (36)		
% biomass mg/m ³	53.8 (143.5)	65.7 (208.7)	97.3 (17.9)	26.2 (47.7)	75.2 (215.1)	90.5 (51.5)		
Pyrrophyta % total cells/mL	-	-	-	0.4 (3)	0.2 (3)	-		
% biomass mg/m ³	-	-	-	26.3 (48.0)	0.8 (2.4)	-		
Cryptophyta % total cells/mL	-	7.1 (95)	-	27.0 (210)	0.3 (6)	-		
% biomass mg/m ³	-	5.9 (18.8)	-	21.7 (39.5)	0.4 (1.1)	-		

(Continued)

Table 13. Continued.

Station Depth (m) Date	9			10		
	0.5 10/07/78	0.5 01/08/77	0.5 08/12/77	0.5 10/07/78	40.0 10/07/78	
Chlorophyta						
<i>Carteria klebsii</i>		5		11	31	
<i>Chlamydomonas</i> spp.		47				
<i>Oocystis Borgei</i>	6					
<i>Oocystis parva</i>	3	28		3		
<i>Monoraphidium arcuatum</i>						
<i>Quadrigula lacustris</i>	3	10		3	3	
<i>Tetraedron minimum</i>						
Chrysophyta						
<i>Aulomonas purdyi</i>		20		28	34	
<i>Bitrichia chodatii</i>		639		34	36	
<i>Chromulina</i> spp.		10				
<i>Chrysochromulina parva</i>		5		1	3	
<i>Chrysolykos planctonicus</i>	1					
<i>Chrysoikos skujae</i>						
<i>Dinobryon attenuatum</i>	1	38				
<i>Dinobryon borgei</i>						
<i>Dinobryon campanulostipitum</i>						
<i>Dinobryon crenulatum</i>						
<i>Dinobryon cylindricum</i>						
<i>Dinobryon divergens</i>						
<i>Dinobryon sertularia</i>						
<i>Dinobryon sociale</i>		47				

(Continued)

Table 13. Continued.

Station Depth (m) Date	9		10		10	
	0.5 10/07/78	0.5 01/08/77	0.5 08/12/77	0.5 10/07/78	40.0 10/07/78	
<i>Dinobryon</i> spp.						
<i>Kephyrion obliquum</i>		57		1	3	
<i>Kephyrion</i> spp.						
<i>Kephyriopsis</i> spp.						
<i>Mallomonas akrokomos</i>	1			4	14	
<i>Mallomonas</i> spp.						
<i>Monosiga varians</i> var. <i>vagans</i>					8	
<i>Ochromonas</i> spp.		52		17	11	
<i>Pseudokephyrion inflatum</i>	4			1	11	
<i>Pseudokephyrion pseudospirale</i>	1					
<i>Pseudokephyrion</i> spp.		5		27	17	
<i>Pseudopedinella erkensis</i>		38			3	
<i>Salpingoeca frequentissima</i>						
<i>Spiniferomonas bourrellii</i>		14		1	14	
<i>Spiniferomonas</i> spp.	3					
<i>Steleomonas dichotoma</i>						
<i>Uroglenopsis americana</i>		10				
Unidentified chrysophyceae						
Bacillariophyta						
<i>Achnanthes lemmermannii</i>						
<i>Achnanthes lanceolata</i>						
<i>Achnanthes minutissima</i>						
<i>Achnanthes</i> spp.						
<i>Amphora coffeiformis</i>						
<i>Amphora ovalis</i> var. <i>pediculus</i>						6
<i>Asterionella formosa</i>						

(Continued)

Table 13. Continued.

Station Depth (m) Date	9		10	
	0.5 10/07/78	0.5 01/08/77	0.5 08/12/77	0.5 10/07/78
<i>Cocconeis placentula</i> var. <i>lineata</i>			18	
<i>Cocconeis</i> spp.				6
<i>Cyclotella comta</i>				
<i>Cyclotella comta</i> var. <i>oligactis</i>	1			6
<i>Cyclotella ocellata</i>				8
<i>Cyclotella atomus</i>			73	84
<i>Cyclotella glomerata</i>	153	1533		
<i>Cymbella minuta</i>				
<i>Cymbella minuta</i> f. <i>latens</i>				
<i>Diatoma tenue</i>				
<i>Diatoma tenue</i> var. <i>elongatum</i>				
<i>Fragilaria pinnata</i>				
<i>Fragilaria</i> spp.				
<i>Navicula tusculea</i>				
<i>Navicula</i> spp.		14		
<i>Nitzschia acicularis</i>				
<i>Pinnularia</i> spp.				
<i>Rhizosolenia eriensis</i>				14
<i>Stephanodiscus hantzschia</i>				
<i>Stephanodiscus</i> spp.				
<i>Synedra acus</i>				
<i>Synedra</i> spp.				

Pyrrophyta

Peridinium inconspicuum

(Continued)

Table 13. Continued.

Station Depth (m) Date	9		10	
	0.5	0.5	0.5	0.5
	10/07/78	01/08/77	08/12/77	10/07/78
<i>Peridinium</i> spp.				
<i>Gymnodinium</i> spp.				
<i>Cryptophyta</i>				
<i>Cryptomonas marsonii</i>		10		6
<i>Cryptomonas</i> spp.				6
<i>Rhodomonas minuta</i>		203	43	213
Total cells/mL	177.0	2790.0	18.0	247.0
Total biomass mg/m ³	43.7	741.0	45.0	33.9
Number of Species	11	21	1	14
$\bar{d}$	0.68	1.53	-	2.09
e	0.18	0.19	-	0.43
Per cent composition of the major groups based upon the total density and total biomass.				
Chlorophyta	total cell total cells/mL	6.8 (12)	3.2 (90)	-
	% total biomass	12.3 (5.4)	2.6 (19.4)	9.1 (3.1)
Chrysophyta	% total cell/mL	6.2 (11)	33.5 (935)	46.2 (114)
				28.7 (154)

(Continued)

Table 13. Continued.

Station Depth (m) Date	9				10			
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	10/07/78	01/08/77	08/12/77	10/07/78	10/07/78	08/12/77	10/07/78	10/07/78
Per cent composition of the major groups based upon the total density and total biomass.								
Chrysophyta								
% biomass mg/m ³	2.0 (0.9)	8.6 (63.6)	-	16.6 (5.6)	11.5 (12.0)			
Bacillariophyta								
% total cells/mL	87.0 (154)	55.4 (1547)	100.0 (18)	29.5 (73)	23.1 (124)			
% biomass mg/m ³	85.6 (37.4)	81.7 (605.2)	100.0 (45.0)	51.5 (17.5)	35.2 (36.6)			
Pyrrophyta								
% total cells/mL	-	0.2 (5)	-	-	-			
% biomass mg/m ³	-	1.2 (8.8)	-	-	-			
Cryptophyta								
% total cells/mL	-	7.6 (213)	-	17.4 (43)	41.9 (225)			
% biomass mg/m ³	-	5.9 (44.0)	-	22.7 (7.7)	46.9 (48.8)			

Table 14. Total density (as cells/mL) and total biomass (as mg/m³) of the phytoplankton from 5 unnamed lakes in the vicinity of Ya-Ya lake, during August, 1977. Also given are the number of species, diversity index ($\bar{d}$), equitability values (e), and the relative abundance of the major groups based upon total density and total biomass.

Site No.	LK A	LK B	LK C	LK D	LK E
Depth (m)	0.5	0.5	0.5	0.5	0.5
Date	05/08	05/08	05/08	05/08	05/08
Chlorophyta					
<i>Ankistrodesmus falcatus</i>		17		59	
<i>Carteria klebsii</i>					7
<i>Chlamydomonas</i> spp.	213	86	462		235
<i>Cosmarium bioculatum</i>	14				35
<i>Crucigenia crucifera</i>				142	
<i>Crucigenia tetrapedia</i>	57	69		142	90
<i>Franceia ovalis</i>	28	17			
<i>Lagerheimia quadriseta</i>		86			
<i>Oocystis Borgei</i>	85				
<i>Oocystis parva</i>	14			177	21
<i>Pediastrum Boryanum</i>				59	
<i>Pediastrum duplex</i>				425	
<i>Quadrigula lacustris</i>		34			48
<i>Scenedesmus bijuga</i>	57				55
<i>Scenedesmus lefevrii</i>				47	
<i>Schroederia setigera</i>				625	
<i>Tetraedron minimum</i>	170	361	107		48
<i>Tetraedron muticum</i>					7
Cyanophyta					
<i>Anabaena</i> spp.		722			83
<i>Chroococcus dispersus</i>				94	
<i>Coelosphaerium</i>					
<i>kuetszingianum</i>	454				
<i>Lyngbya limnetica</i>		3801			
Chrysophyta					
cf. <i>Amphimonas</i>					69
<i>Bicoeca parva</i>				12	
<i>Bicoeca</i> spp.			36		
<i>Bitrichia chodatii</i>					21
<i>Chromulina</i> spp.	1207	310	36	83	104
<i>Chrysochromulina parva</i>	795	843	497		269
<i>Dinobryon attenuatum</i>			36		
<i>Dinobryon bavaricum</i>		155			
<i>Dinobryon borgei</i>		17	36		35
<i>Dinobryon</i>					
<i>campanulostipitum</i>					

(Continued)

Table 14. Continued.

Site No.	LK A	LK B	LK C	LK D	LK E
Depth (m)	0.5	0.5	0.5	0.5	0.5
Date	05/08	05/08	05/08	05/08	05/08
<i>Dinobryon crenulatum</i>	14	17			214
<i>Dinobryon cylindricum</i>	298				
<i>Dinobryon sociale</i>	14	447			345
<i>Dinobryon suecicum</i> var. <i>longispum</i>	14				
<i>Dinobryon</i> spp.			36		
<i>Epipyxis alaskana</i>		155			
<i>Kephyrion</i> spp.	14				
<i>Mallomonas akrokomos</i>				12	
<i>Mallomonas</i> spp.			36	12	
<i>Monosiga varians</i> var. <i>vagans</i>	28	447		12	35
<i>Ochromonas</i> spp.	327	396	107	35	200
<i>Pseudokephyrion</i> <i>alaskanum</i>					14
<i>Pseudokephyrion</i> <i>pseudospirale</i>				24	
<i>Pseudokephyrion</i> <i>undulatissimum</i>					21
<i>Pseudokephyrion</i> spp.					179
<i>Pseudopedinella erkensis</i>	28	206	36		28
<i>Spiniferomonas bourrellii</i>		52	36		
<i>Stelexomonas dichotoma</i>					
<i>Syncrypta</i> sp.		103			
<i>Uroglena volvox</i>	398		72		
Unidentified chrysophytes?	610			47	
Xanthophyta					
<i>Ophiocytium parvulum</i>		17			
Bacillariophyta					
<i>Achnanthes minutissima</i>		17			
<i>Achnanthes</i> spp.				12	
<i>Asterionella formosa</i>		69			
<i>Cyclotella</i> spp.	14	292	711	35	55
<i>Diatoma tenue</i> var. <i>elongatum</i>		17			
<i>Navicula pupula</i> var. <i>rectangularis</i>				12	
<i>Nitzschia palea</i>		17			
<i>Nitzschia</i> spp.					12
<i>Rhizosolenia eriensis</i>		34	142		104
<i>Synedra acus</i> var. <i>radians</i>					14

(Continued)

Table 14. Continued.

Site No.	LK A	LK B	LK C	LK D	LK E
Depth (m)	0.5	0.5	0.5	0.5	0.5
Date	05/08	05/08	05/08	05/08	05/08
<i>Synedra acus</i>					
<i>delicatissima</i>					41
<i>Synedra</i> spp.	28				
<i>Tabellaria fenestrata</i>		17			
Euglenophyta					
<i>Euglena polymorpha</i>		17			
<i>Trachelomonas</i> spp.		17			
Pyrrophyta					
<i>Gymnodinium</i> spp.		17			
<i>Peridinium inconspicuum</i>	14				
<i>Peridinium</i> spp.		17			7
Cryptophyta					
<i>Cryptomonas marsonii</i>				47	
<i>Cryptomonas ovata</i>			213		
<i>Cryptomonas</i> spp.					7
<i>Rhodomonas minuta</i>	43	86	391	991	76
Total cells/mL	4938	8975	2990	3116	2467
Total biomass mg/m ³	561.1	1450.9	714.6	534.0	562.7
Number of species	25	34	17	23	30
$\bar{d}$	2.38	2.31	2.28	2.23	2.93
e	0.28	0.21	0.41	0.26	0.37
Chlorophyta	12.9	7.5	19.0	53.8	22.1
total cells/mL	(638)	(670)	(569)	(1676)	(546)
biomass mg/m ²	27.5	6.4	15.2	45.0	16.4
	(154.4)	(93.2)	(108.5)	(240.4)	(92.1)
Cyanophyta					
total cells/mL	9.1	50.3	-	3.0	3.4
	(454)	(4523)		(0.9)	(83)
biomass mg/m ²	1.6	4.1	-	0.2	0.4
	(9.1)	(59.7)		(0.9)	(2.5)
Chrysophyta	75.9	35.1	32.2	7.6	62.2
total cells/mL	(3747)	(3148)	(964)	(237)	(1534)
biomass mg/m ²	60.9	35.9	12.0	9.5	61.1
	(341.7)	(521.3)	(86.1)	(50.9)	(343.9)

(Continued)

Table 14. Continued.

Site No.	LK A	LK B	LK C	LK D	LK E
Depth (m)	0.5	0.5	0.5	0.5	0.5
Date	05/08	05/08	05/08	05/08	05/08
Bacillariophyta	0.9	5.1	28.5	2.3	8.7
total cells/mL	(42)	(463)	(853)	(71)	(214)
biomass mg/m ²	6.6	13.4	25.7	5.3	16.2
	(37.0)	(193.7)	(183.4)	(28.2)	(91.2)
Euglenophyta	-	0.4	-	-	-
total cells/mL		(34)			
biomass mg/m ²	-	13.2	-	-	-
		(190.9)			
Pyrrophyta	0.3	0.4	-	-	0.3
total cells/mL	(14)	(34)			(7)
biomass mg/m ²	2.0	20.8	-	-	2.2
	(11.2)	(301.8)			(12.3)
Cryptophyta					
total cells/mL	0.9	1.0	20.2	33.3	3.4
	(43)	(86)	(604)	(1038)	(83)
biomass mg/m ³	1.4	5.9	47.1	40.0	3.7
	(7.7)	(86.0)	(336.6)	(213.6)	(20.7)
Xanthophyta	-	0.2	-	-	-
total cells/mL		(17)			
biomass mg/m ³	-	0.7	-	-	-
		(4.3)			

25 from Lake A, 34 from Lake B, 17 from Lake C, 23 from Lake D, and 30 from Lake E (Table 11).

Ya-Ya Lake

Dominance of Major Taxa. Figure 10 compares the three major regions of Ya-Ya Lake in terms of dominance indices for five major groups of phytoplankton. (One major group, the Cyanophyta, common in many lakes, is absent from Ya-Ya Lake). It is a summation of data for all three sampling periods. The data show that overall, the Bacillariophyta (Diatoms) were the most numerous group dominating the phytoplankton in Regions I and II and second in importance only to the Chrysophyta in Region III. Second in overall importance were the Chrysophyta. This group was second in importance to the Bacillariophyta in Regions I and II but dominated Region III. Third in overall importance were the Cryptophyta which were of moderate importance in each of the three regions. They were followed in overall importance by the Chlorophyta (green algae). The latter were more important in Regions I and III than in Region II. The least important group in terms of its dominance index was the Pyrrophyta (Dinoflagellates). These were absent from Regions I and II but were present in small numbers in Region III.

Figure 11 compares the dominance indices of the five major groups during the three sampling periods (August 1977, December 1977, and July 1978) combining data for all stations.

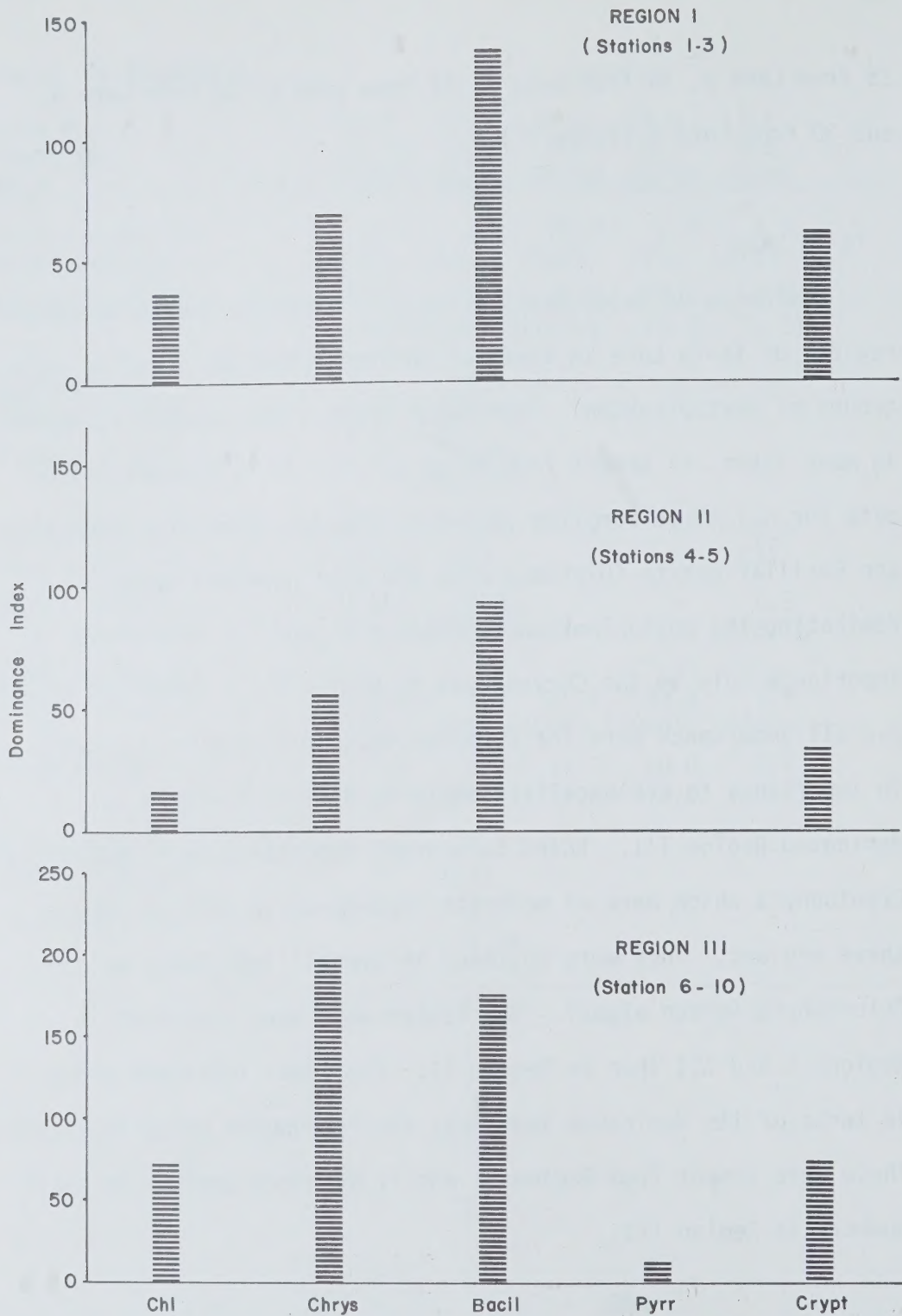


Figure 10. Dominance index for all major groups of algae from the three regions of Ya-Ya Lake throughout the study period.

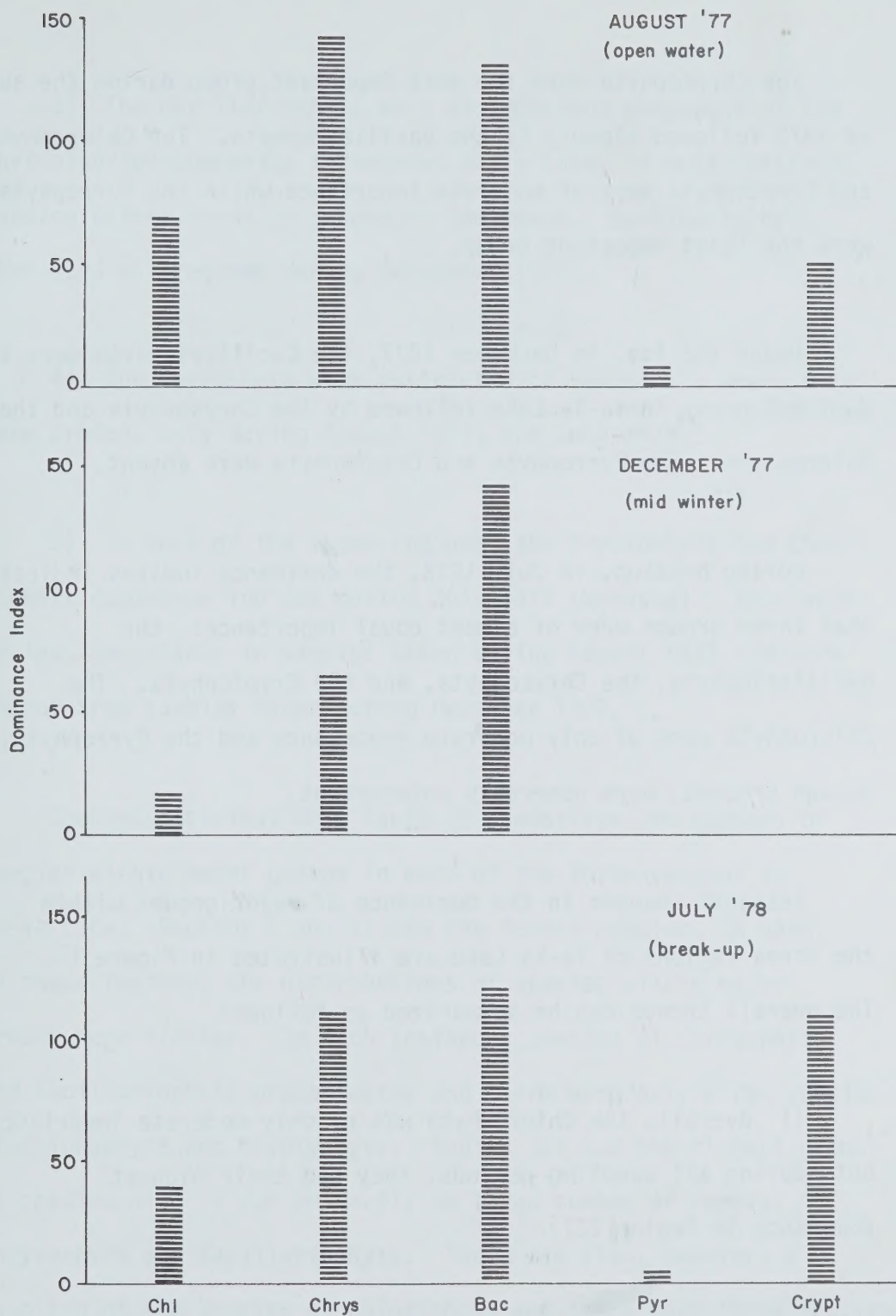


Figure 11. Dominance index for all major groups of algae during August and December 1977 and July 1978 from all regions of Ya-Ya Lake.

The Chrysophyta were the most important group during the summer of 1977 followed closely by the Bacillariophyta. The Chlorophyta and Cryptophyta were of moderate importance while the Pyrrophyta were the least important group.

Under the ice, in December 1977, the Bacillariophyta were the dominant group in Ya-Ya Lake followed by the Chrysophyta and the Chlorophyta. The Pyrrophyta and Cryptophyta were absent.

During breakup, in July 1978, the dominance indices indicate that three groups were of almost equal importance: the Bacillariophyta, the Chrysophyta, and the Cryptophyta. The Chlorophyta were of only moderate importance and the Pyrrophyta, though present, were generally unimportant.

Seasonal changes in the dominance of major groups within the three regions of Ya-Ya Lake are illustrated in Figure 12. The overall trends can be summarized as follows:

- 1) Overall, the Chlorophyta was of only moderate importance but, during all sampling periods, they had their highest dominance in Region III.

- 2) In all sampling periods, the Chrysophyta were of much greater importance in Region III than in Regions I or II.

3) The Bacillariophyta were an important component of the phytoplankton community throughout Ya-Ya Lake, in most instances ranking either first or second in dominance. Bacillariophyta dominated all regions during December, 1977.

4) The Pyrrophyta were restricted to Region III where they were present only during August 1977, and July 1978.

5) In each of the three regions, the Cryptophyta had their highest dominance indices during July 1978 (breakup). They were of less importance in samples taken during August 1977 and were absent from samples taken during December 1977.

Species Distribution. Table 15 summarizes the numbers of species within major groups in each of the three regions in Ya-Ya Lake. Regions I and II had the fewest species, 32 each. In these regions, the distributions of species within major groups were similar. In each instance, species of Chrysophyta and Bacillariophyta predominated and there were only a few species of Chlorophyta and Cryptophyta. Region III had the highest number of species with 79 due primarily to large number of species of Chrysophyta and Bacillariophyta. There was also, however, a doubling of the species of Chlorophyta and there were three species of Pyrrophyta, a group absent from Regions I and II.

There were five phytoplankton species which were found

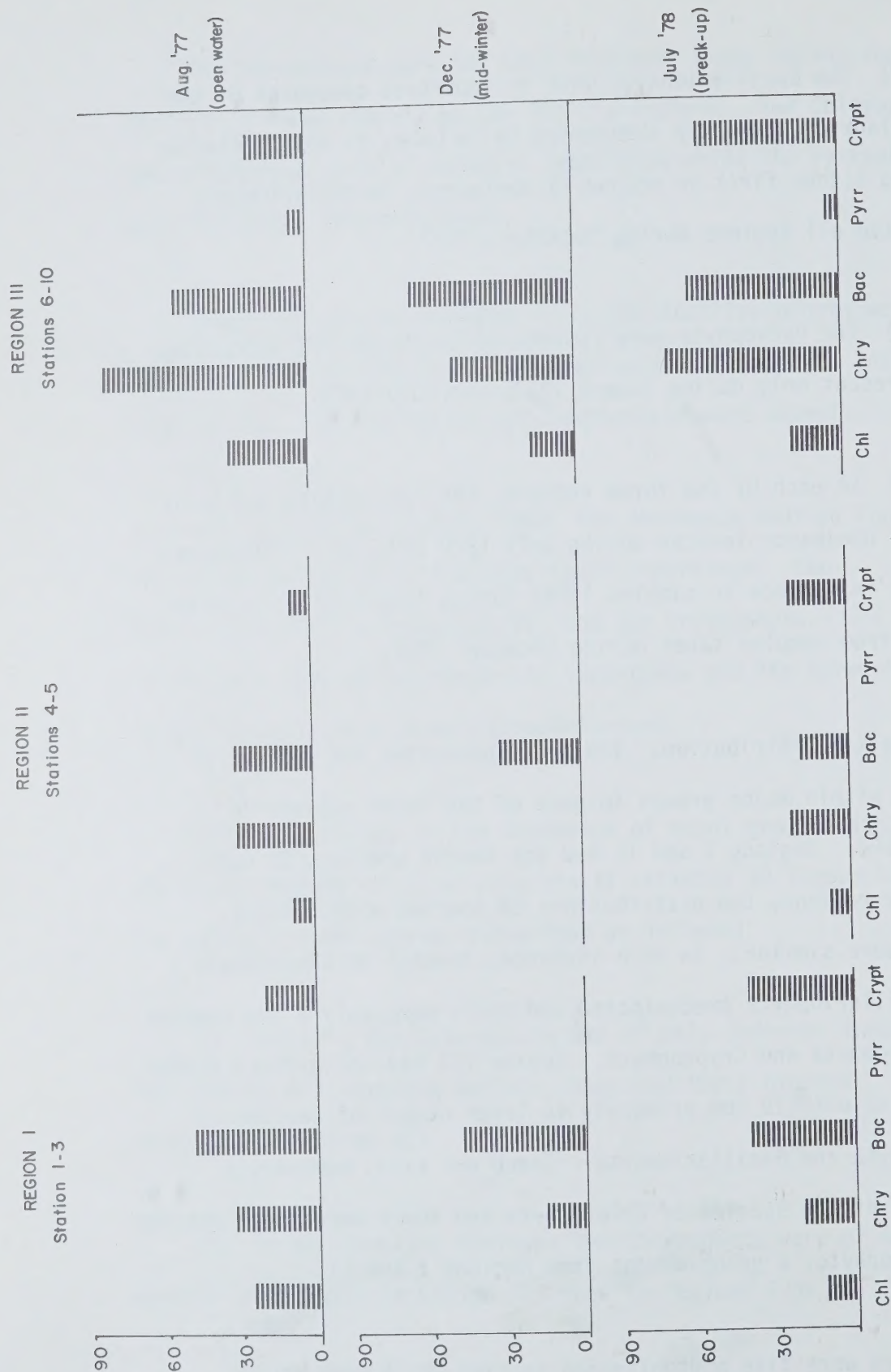


Figure 12. Dominance index for all major groups of algae from the three regions of Ya-Ya Lake during August and December 1977 and July 1978.

Table 15. Numbers of species of phytoplankton within major groups summarized by regions. Data summarized for all phytoplankton samples from Ya-Ya Lake, 1977 and 1978.

Region Major Group	I	II	III	All Regions
Chlorophyta	4	2	8	10
Chrysophyta	11	15	33	34
Bacillariophyta	15	13	32	42
Pyrrophyta	-	-	3	3
Cryptophyta	2	2	3	3
Total	32	32	79	92

throughout Ya-Ya Lake and which, at one time or another, dominated samples in each of the three regions (Figure 13). Peak mean cell counts of all five species--*Chlamydomonas* spp. (Chlorophyta), *Chrysochromulina parva* and *Dinobryon sociale* (Chrysophyta), *Cyclotella glomerata* (Bacillariophyta), and *Rhodomonas minuta* (Cryptophyta)--were recorded in Region III, the least turbid area of Ya-Ya Lake. All five algal species have been previously recorded as important members of the phytoplankton communities in Arctic lakes. Hobbie et al. (1973) found that *Chlamydomonas* spp. were important members of the phytoplankton communities of clear lakes in Alaska but they were an insignificant component of the community in a seasonally very turbid lake. *Chrysochromulina parva* and *Dinobryon sociale*, both motile Chrysophyta species, are important components of the phytoplankton throughout the Northwest Territories (Moore, 1978). *Cyclotella glomerata* has been previously described as a dominant form in samples of algae from lake sediments from the Tuktoyaktuk Peninsula (Koivo and Ritchie, 1978), and in a large number of lakes and streams through the Northwest Territories (Moore, 1978). *Cyclotella* has been recorded as an important member of the phytoplankton in previous studies of the North Basin (Region III) of Ya-Ya Lake and other deep upland lakes in the Parsons Lake-Richards Island area (McCart et al., 1976).

Density. Figure 14 compares data describing turbidity and suspended sediment concentrations with mean values for the total density (as cells/ml) of phytoplankton at sampling stations in

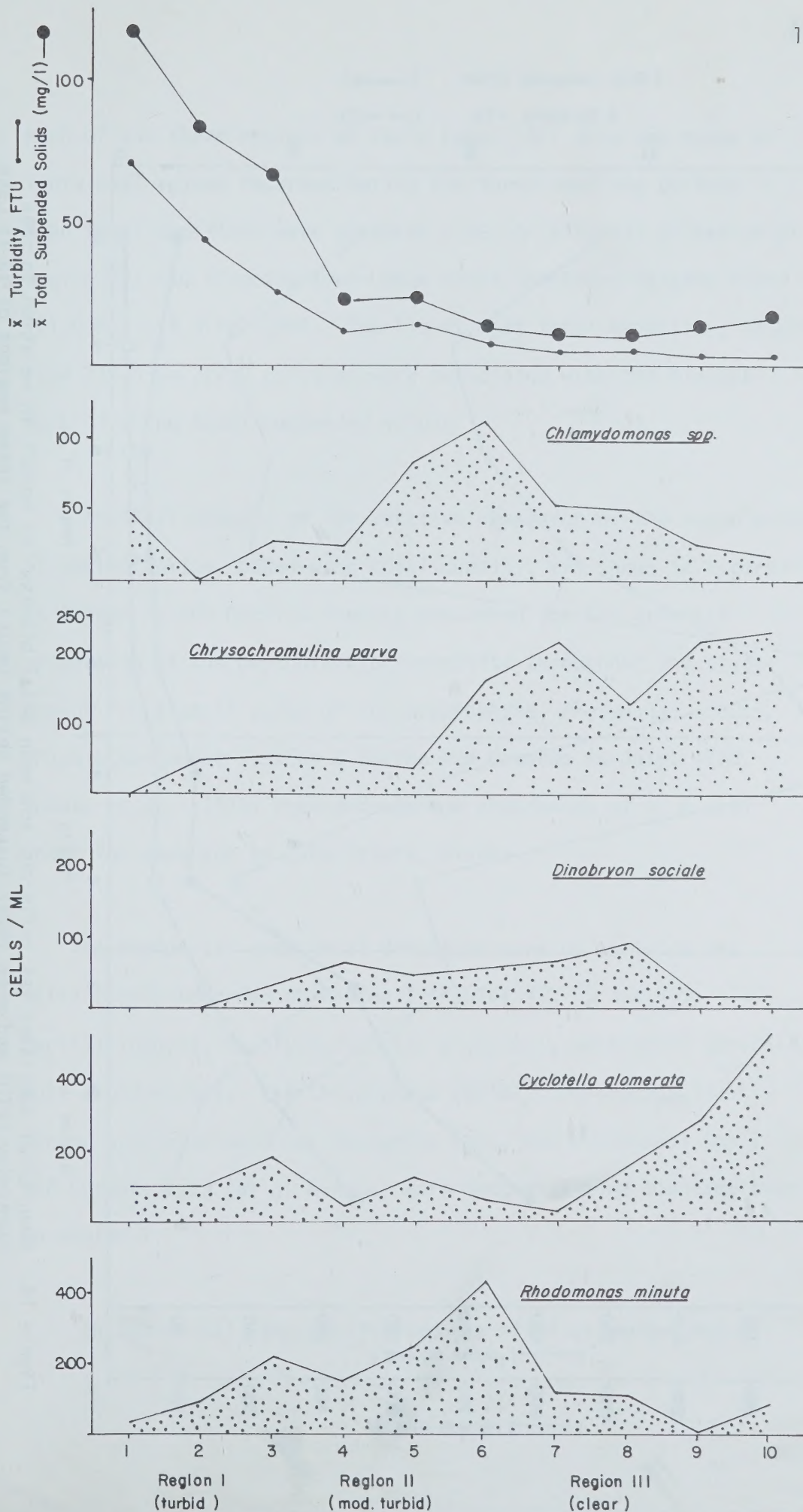


Figure 13. Total densities (as cells/mL) for five dominant algal species from the three regions of Ya-Ya Lake in relation to mean turbidity (FTU) and mean total suspended solids (mg/L).

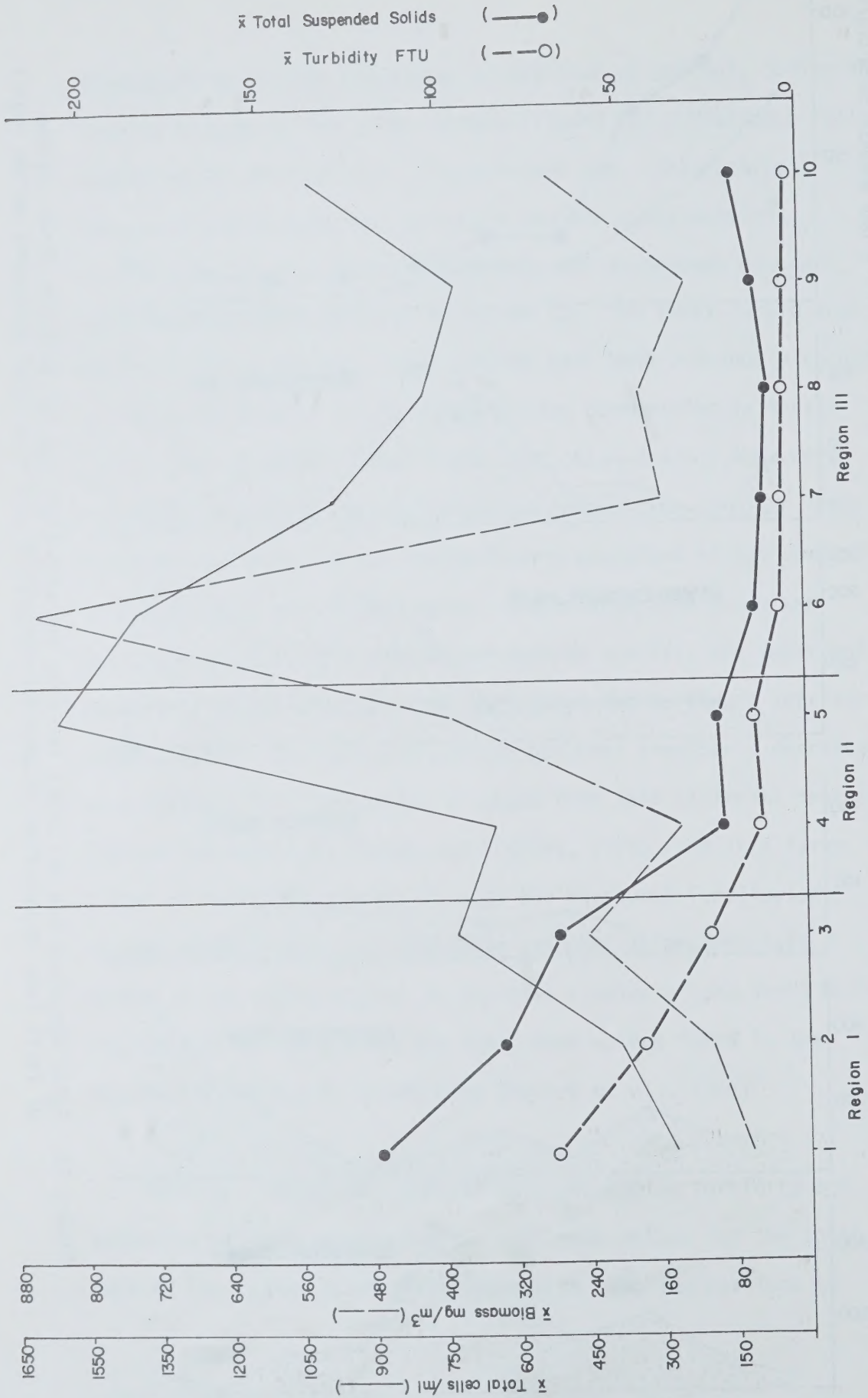


Figure 14. Mean total densities (as cells/mL) and mean total biomass (as mg/m³) in relation to mean turbidity (FTU) and mean total suspended solids (mg/L) from the three regions of Ya-Ya Lake.

each of the three regions of Ya-Ya Lake. All data are means of individual values recorded during the three sampling periods. Mean total densities were greatest (1565.0 cells/ml) in Region II. Region III had slightly lower mean total densities ranging from 711.0 to 1318.0 cells/ml. The lowest mean total densities, ranging from 279.0 to 727.0 cells/ml were associated with the highest turbidity and total suspended values.

Seasonal changes in the relative abundance of the major groups of phytoplankton, based upon total density, are shown in Figure 15. In Region I, the Bacillariophyta accounted for the greatest proportion of the phytoplankton community throughout the study except for a small pulse of the cryptophyte, *Rhodomonas minuta*, which occurred at Station 2 during ice breakup in July, 1978. Hobbie et al. (1973) recorded maximum abundances of *R. minuta* under the June ice in Lake Peters, Alaska.

In Region II, peak total densities were up to twice the total counts recorded at Region I (Tables 12, 13 and 15). The Bacillariophyta, mainly *Cyclotella glomerata*, were still generally most abundant but, the Chrysophyta (mainly *Chrysochromulina parva*, *Dinobryon sociale*, *Kephyrion* spp., and *Ochromonas* spp.) and Chryptophyta (as *R. minuta*) were generally more abundant than in Region I.

In Region III, the Bacillariophyta still accounted for a

substantial portion of the phytoplankton population, but the Chrysophyceae were increasingly important even in comparison with their abundance in Region II. Another important difference between Region III and the other two regions was the appearance of the Pyrrophyta which were not found elsewhere in the lake.

Biomass. Overall, Region III, the least turbid area of Ya-Ya Lake, supported the highest mean total biomass ranging from 0.2 to 2753.0 mg/m³. These values are somewhat lower than, but within the range of, biomass values recorded from other lakes in the Parsons Lake-Richards Island area of the Northwest Territories (McCart et al., 1976).

Mean total biomass was intermediate in Region II (ranging from 7.9 to 997.0 mg/L) and lowest (ranging from 12.2 to 384.7 mg/m³) in Region I (Table 12), the area of highest turbidity and total suspended solid values (Figure 14).

The pattern of seasonal change in the relative abundance of major groups based on total biomass (Figure 16) is very similar to that based on total densities (Figure 15). The only significant change was the appearance of Pyrrophyta (dinoflagellates) in Region III during ice breakup in July 1978. One dinoflagellate, *Gymnodinium* spp., accounted for 81.4% of the total biomass. The dramatic appearance of *Gymnodinium* may have been related to the dramatic decline in the biomass of the centric diatom *Cyclotella*

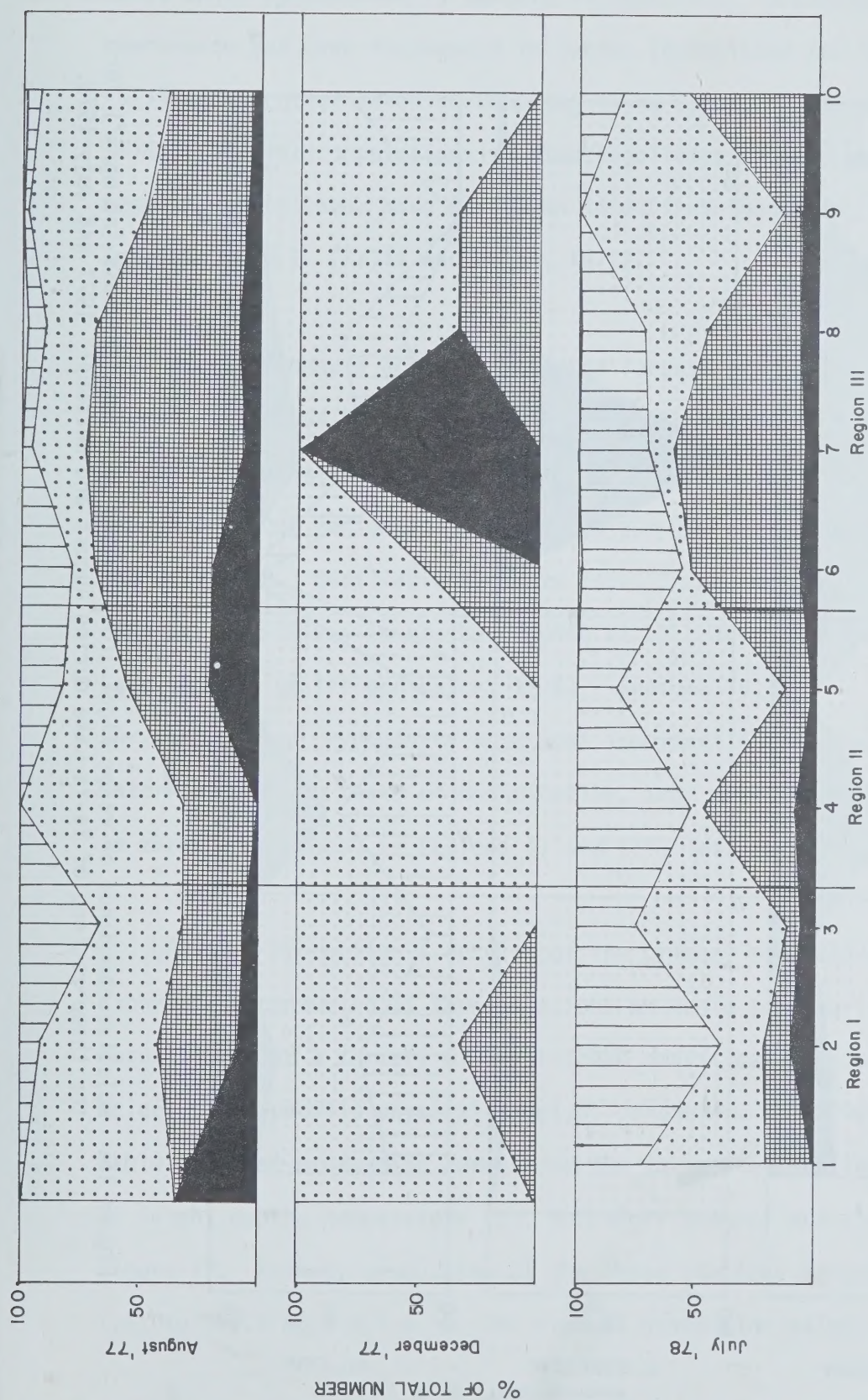


Figure 15. Relative abundance of major algal groups based upon total number (as cells/mL) for the three regions of Ya-Ya Lake during August and December 1977 and July 1978.

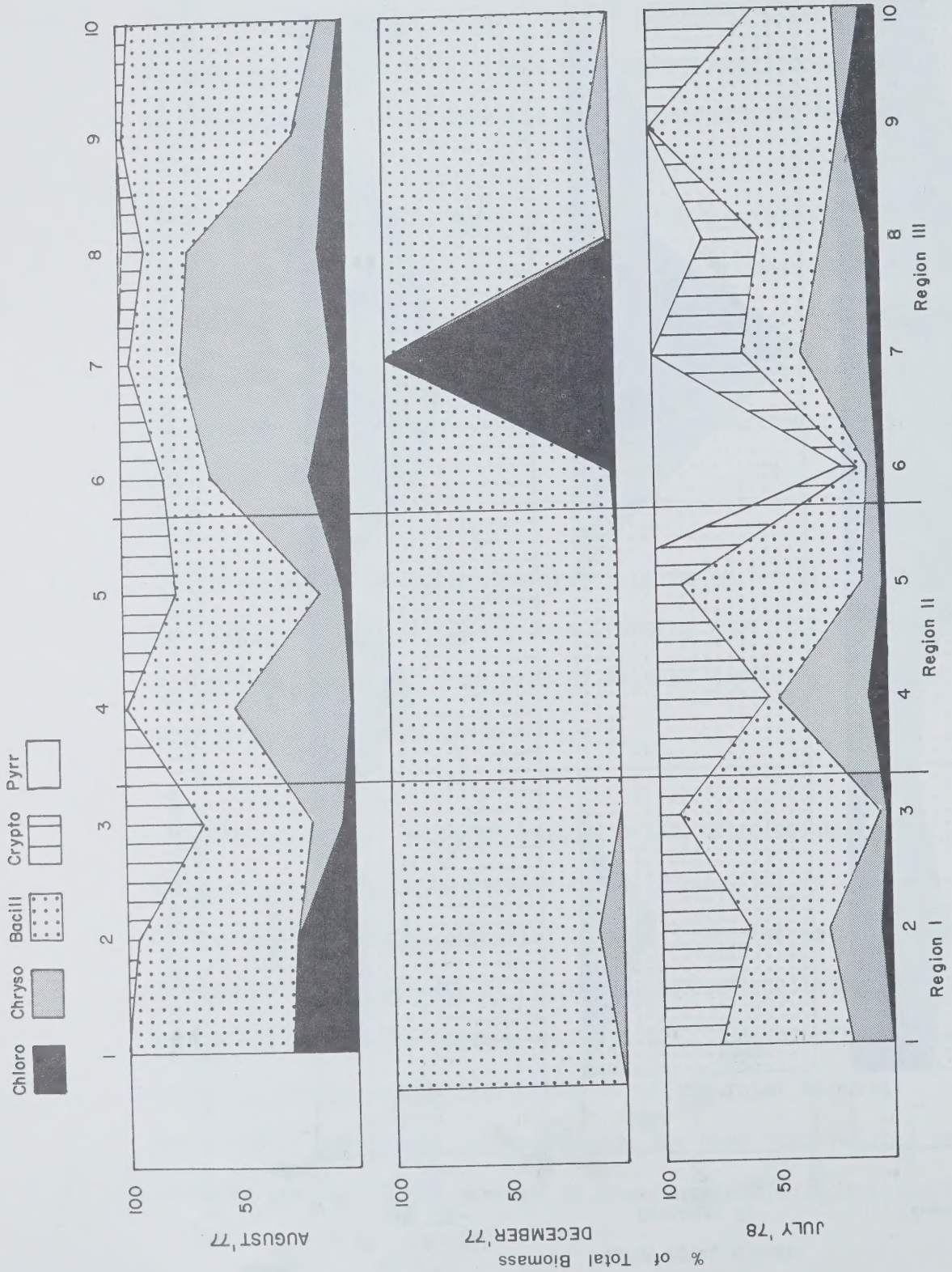


Figure 16. Relative abundance of major algal groups based upon total biomass (as mg/m^3) for the three regions of Ya-Ya Lake during August and December 1977 and July 1978.

spp., which *Gymnodinium* is capable of ingesting. A similar phenomenon has been documented in Sweden (Bertilsson and Gelin, 1975) and in other lakes surrounding Ya-Ya Lake (McCart et al., 1976). Sizeable populations of dinoflagellates in deep water beneath an ice cover have also been noted from Char Lake, at Resolute, N.W.T. (Kalff and Welch, 1974).

Bacillariophyta accounted for the largest proportion of biomass at Region I and during the winter in all regions of Ya-Ya Lake. High biomass of Bacillariophyta were also found in the deeper areas of Region III (Stations 9 and 10) during August 1977 and July 1978. Bacillariophyta are known to be important in deep northern lakes in Alaska (Hobbie et al., 1973) and in Char Lake, N.W.T. (Kalff and Welch, 1974). Seasonally, the Chrysophyta and Cryptophyta were most important during the open water season. In terms of distribution, they were most important, in terms of biomass, in Regions II and III, less so in Region I.

Primary Production. Results of the primary production experiments conducted at three stations on Ya-Ya Lake during August 1977 and a summary of their total densities and biomass values, and specific physical-chemical parameters are given in Table 16. Net production curves for the three stations in relation to Secchi depth, temperature (C), and algal biomass are shown in Figure 17. Primary production at the three stations ranged from 1.41 to 129.6 mg C m⁻² d⁻¹. The highest production values were

Table 16. Summary of data for primary production ($\text{mg C m}^{-3} \text{d}^{-1}$) total density (cells/mL), total biomass (mg/m^3), chlorophyll a ($\mu\text{g/L}$), Secchi depth (m), turbidity values (FTU), total suspended solids (mg/L), for stations 2, 6, and 8 on Ya-Ya Lake.

Stations	2		6		8	
	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range
1° production $\text{mg C m}^{-3} \text{d}^{-1}$	-	1.41* -	-	129.6*	-	33.8* -
Total density (cells/mL)	386.8	54.0 - 852.0	1406.0	71 - 2313.0	949.9	54.0-1468.0
Total biomass (mg/m^3)	109.2	12.2 - 224.8	761.2	45.4-2753.0	256.7	18.4- 335.6
Chlorophyll a ($\mu\text{g/L}$)	2.0	<1.0 - 2.0	2.5	2.0-3.0	1.0	0 - 2.0
Secchi depth (m)		0.04		0.8		2.0
Turbidity values (FTU)	44.6	8.7 - 73.0	7.2	4.0-11.0	5.2	1.3- 9.6
Total suspended solids (mg/L)	83.9	39.7 - 121.3	13.8	3.3-34.0	9.9	1.4- 30.9

* actual values

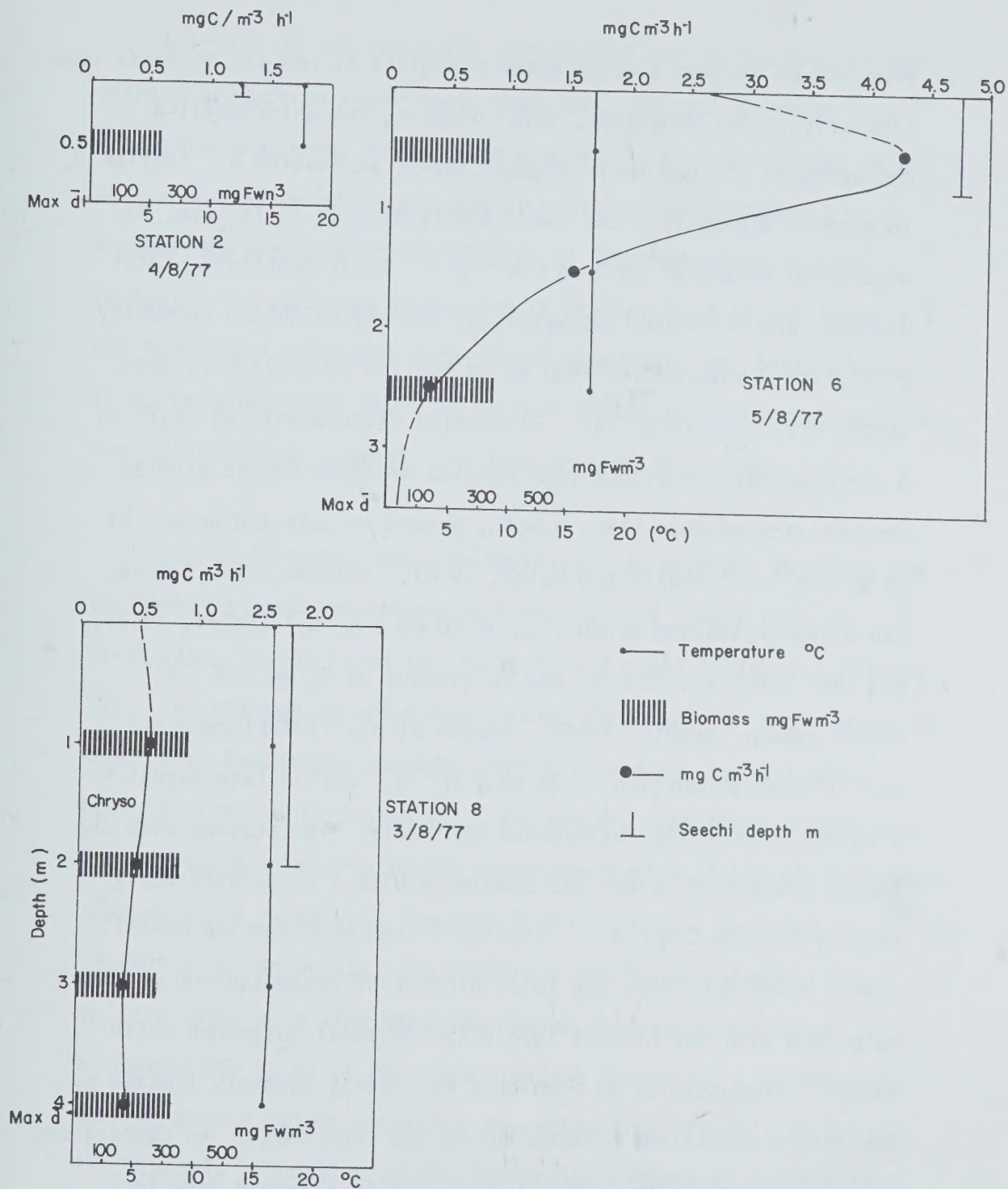


Figure 17. Ya-Ya Lake Stations 2, 6, and 8: Secchi depth, phytoplankton biomass, and primary production, during August 1977.

recorded at Station 6 which borders Regions II and III on Ya-Ya Lake. Similarly, total densities, total biomass, and chlorophyll-a measurements all had their highest levels at Station 6. Station 8, located in Region III, the least turbid area of Ya-Ya Lake, had production values of $33.8 \text{ mg C m}^{-2} \text{ d}^{-1}$. Total densities, total biomass, and chlorophyll-a values of the phytoplankton community at Station 8 were not as high as at Station 6, a slightly more turbid area (see Table 16). Production measurements at Stations 6 and 8 appear consistent with results of other Arctic studies. Productivity of Char Lake, N.W.T., peaked in July and August at $70 \text{ mg C m}^{-2} \text{ d}^{-1}$ (Kalff and Welch, 1974); Imikpuk Lake, Alaska, had a summer average production of $70 \text{ mg C m}^{-2} \text{ d}^{-1}$ (Kalff, 1967); and Lake Schrader, Alaska, had an average of $72 \text{ mg C m}^{-2} \text{ d}^{-1}$ during summer (Hobbie, 1964). Sheath et al. (1975b) recorded peak primary production of $46 \text{ mg C m}^{-2} \text{ d}^{-1}$ during late August in a tundra pond on the Tuktoyaktuk Peninsula. The station with the lowest production values was Station 2 with a calculated daily rate of $1.41 \text{ mg C m}^{-2} \text{ d}^{-1}$. Station 2 also recorded the overall lowest total densities and total biomass of phytoplankton which coincided with the highest turbidity and total suspended solid values. Productivity at Station 2 was likely severely limited by the turbid conditions present during the experiment. In comparison, primary production experiments conducted on a turbid lake in Alaska, Lake Peters, yielded production values of $0.6\text{--}14 \text{ mg C m}^{-2} \text{ d}^{-1}$ (Hobbie, 1964).

Analysis of the community composition during the time of the primary production experiments show that, Station 6, where peak production occurred, had a large proportion of Cryptophyta, mainly *Rhodomonas minuta* which was not as prevalent at Stations 2 or 8. Whether the presence of one species of Cryptophyta could have accounted for the high production at Station 6 it is not known, but from other pertinent data, total densities, and total biomass, it would appear that there is another factor or factors stimulating the phytoplankton community in that area of Ya-Ya Lake.

Species Diversity and Equitability. In general, $\bar{d}$ values and the number of species increased from the most turbid area of Ya-Ya Lake, Region I, to the least turbid area, Region III (Figure 18). The maximum recorded mean values for $\bar{d}$ and for the numbers of species at individual stations were 2.55 and 22, respectively, both at stations in Region III. Evidently, conditions at the more turbid stations restricted the development of a stable phytoplankton community. A relatively low mean $\bar{d}$ value (1.25), recorded at Station 9 in Region III, was primarily due to an extremely low $\bar{d}$ in July 1978, at a time when the diatom *Cyclotella glomerata* accounted for 86.4% of the phytoplankton community. In contrast with $\bar{d}$, mean e values generally decreased from Region I to Region III, largely a function of the increasing numbers of species from Region I to Region III. In Region III, there are more species with a greater disproportion in the numbers of the abundant and rare species.

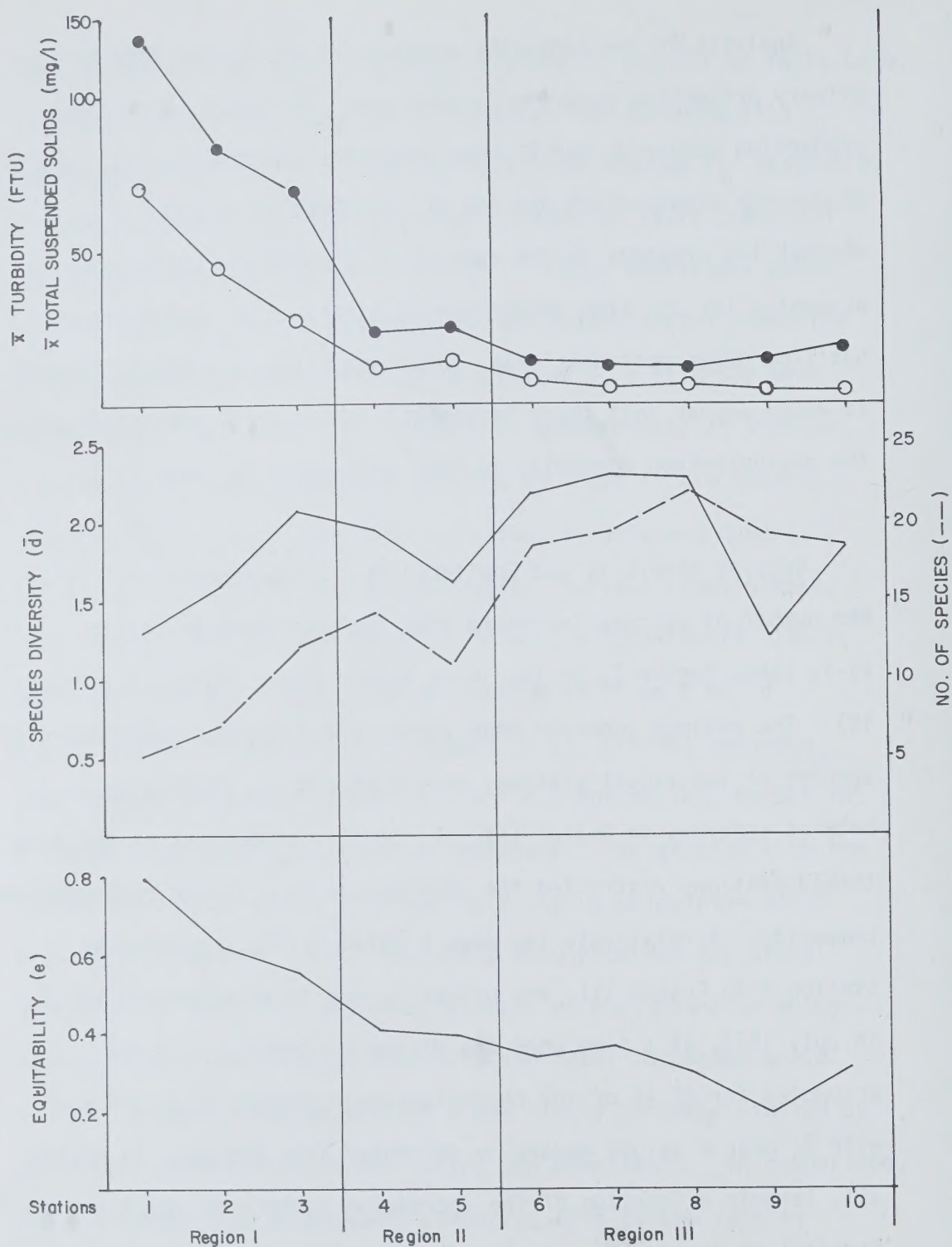


Figure 18. Mean species diversity ($\bar{d}$), mean equitability values, and mean number of species for all stations in the three regions of Ya-Ya Lake during the study. Mean turbidity values (FTU) and mean total suspended solids (mg/L) are also shown.

The Unnamed Lakes

Data describing the phytoplankton communities of the five unnamed lakes are presented in Table 14. In general, total densities (as cells/mL) were much greater than in Ya-Ya Lake. Total densities in August ranged from 2467 to 8975 cells/mL compared to an August peak of 2790 cells/mL (Station 10) at Ya-Ya Lake. Biomass values (534.0-1450.9 mg/m³) were, however, similar to those for Ya-Ya Lake and to the range of 225-1500 mg/m³ reported by Alexander and Coulon (1973) for Alaskan tundra ponds. In terms of community composition, the phytoplankton communities of the unnamed lakes, except for Lake C, were similar. In comparison with Ya-Ya Lake, there was a noticeable lack of Bacillariophyta and a proportionately greater representation of Chlorophyta, Cyanophyta, and Cryptophyta. Based upon community composition, i.e., the absence of Cyanophyta, the relatively small proportion of the Chlorophyta, and the presence of the dominant species *Chlamydomonas* spp., *Chrysochromulina parva*, *Cyclotella glomerata*, and *Rhodomonas minuta*, Lake C was the lake most similar to Region III in Ya-Ya Lake.

Diversity indices and equitability values for the unnamed lakes are slightly higher but comparable to the values recorded in Region III of Ya-Ya Lake.

Conclusions

1. A total of 123 algal species was identified from Ya-Ya Lake and the five unnamed lakes.
2. Bacillariophyta (diatoms) was an important group in Regions II and III of Ya-Ya Lake. The Chrysophyta were next in overall importance and increased in importance from Region I to Region III.
3. The Cryptophyta were of moderate importance in all regions of Ya-Ya Lake followed by the Chlorophyta and the Pyrrophyta which were of least overall importance.
4. Numbers of species were highest in Region III of Ya-Ya Lake due to large increases in species numbers among the Chrysophyta and Bacillariophyta.
5. Five of the dominant species, *Chlamydomonas* spp., *Chrysochromulina parva*, *Dinobryon sociale*, *Cyclotella glomerata*, and *Rhodomonas minuta* produced their peak mean cell counts in Region III.
6. Mean total densities peaked in Region II while total biomass values peaked in Region III. Region I had the lowest mean total densities and total biomass values.

7. Primary production values ($\text{mg C m}^{-2} \text{ d}^{-1}$) at three sites in Ya-Ya Lake ranged from 1.41 to 129.6 $\text{mg C m}^{-2} \text{ d}^{-1}$ and were highest in Region III. The production values are consistent with the results of other studies of primary productivity in the Arctic.

8. The lowest primary production rates were recorded in Region I, probably a response to the high turbidity and total suspended solids in that area.

9. Production rates at Region I correspond closely to productivity values recorded in a turbid lake in Arctic Alaska.

10. Species diversity indices and the number of species tended to increase from the very turbid area of Ya-Ya Lake (Region I) to the least turbid area (Region III).

11. In the five unnamed lakes, total densities and biomass of the phytoplankton were generally greater than in Ya-Ya Lake.

12. Bacillariophyta were of considerably less importance in the unnamed lakes than in Ya-Ya Lake.

13. Of the five unnamed lakes, Lake C showed the greatest similarities to Region III of Ya-Ya Lake.

ZOOPLANKTON

By

D.W. Mayhood, M.Sc.

ZOOPLANKTON

Introduction

The objectives of the zooplankton study were:

- 1) to compare species distribution, abundance, diversity, and equitability in silted and unsilted portions of Ya-Ya Lake;
- 2) to determine if nearby lakes can be used as control sites against which changes in Ya-Ya Lake zooplankton can be measured; and
- 3) to determine if zooplankters show diel shifts in vertical distribution in an Arctic lake during 24-hour daylight.

Methods

Samples were collected with a Wisconsin-style plankton net (mouth diameter 12 cm, mesh aperture 65 to 70 μm) by making three successive vertical hauls at approximately 0.5 m/s from bottom to surface. The contents of the three hauls from each station on each sampling date were pooled to form a single sample, and were preserved in 5% formalin buffered to pH 7.0 to 7.3 with sodium tetraborate. Depth at each station was measured so that the volume of water sampled could be calculated. Collections were made once in each of August 1977, December 1977, and July 1978 in Ya-Ya Lake;

and once in August 1977 in the survey lakes A to E.

Diel vertical migration by zooplankton was studied at Station 8 (depth 4 m) on August 4 and 5, 1977. The weather was calm (wind ≤ 8 km/h), sunny but hazy, cloudless, and warm for the duration of the study. Pyrheliometer records are available for the sampling period (see Phytoplankton section). Samples were collected at 0.5, 2, and 4 m at 0900 h August 4, and at 4 h intervals thereafter up to and including 0900 h August 5, with a 31.25-L Patalas-Schindler plankton trap (Schindler, 1969). Each sample was preserved as described above.

In the laboratory, organisms were identified and counted under a stereoscopic dissecting microscope (to 50x magnification). Usually, the entire sample was examined and counted, but large samples were divided into two to four aliquots with a plankton splitter, then the contents of a single aliquot were identified and counted. Identifications were made with the aid of keys and descriptions in Wilson and Yeatman (1959), Brooks (1957, 1959), Deevey and Deevey (1971), Edmondson (1959), Brandlova et al. (1972), and Ruttner-Kolisko (1972).

Bias-corrected Shannon-Weaver diversity indices ($\bar{d}$) $\pm$ standard error (SE) were calculated according to the formulae provided by Poole (1974:391-393). Equitability indices (e) were estimated from Table 1 of Lloyd and Ghelardi (1964). The rationale for

calculating $\bar{d}$ and e is described in the section on Phytoplankton.

Filtration efficiencies of plankton nets similar to that used in this study can fall within the range of 15 to 30%, but are usually near the lower end of the range (e.g., Rawson, 1942; Anderson, 1967, 1968, 1970). In this study, a net filtration efficiency of 18% was assumed in the calculation of zooplankton densities.

Results and Discussion

Species Composition

The zooplankton species found in Ya-Ya Lake are listed in Tables 17 to 19. The most abundant Crustacea were *Diacyclops bicuspidatus thomasi*, *Cyclops scutifer*, and *Diaptomus sicilis*. Less common were *Epischura lacustris*, *E. nevadensis*, *Limnocalanus macrurus*, *Bosmina longirostris*, and *Daphnia retrocurva*. *Daphnia middendorffiana* was found in small numbers at a single station in the winter samples. The most abundant rotifer found was an unidentified aloricate form, but both *Keratella cochlearis* and *Kellicottia longispina* were also present.

Most of the species present in the plankton in the summer of 1978 were absent from the plankton in the winter of 1977, and were not mature enough to be identified in, or were absent from, the plankton in the spring of 1978. It is very likely that in winter

Table 17. Zooplankton abundance (number per litre), diversity ($\bar{d}$) and equitability (e) in Ya Ya Lake, late July - early August, 1977.

Station Depth (m)	1 2.0	2 5.3	3 1.9	4 2.2	5 2.0	6 5.4	7 3.1	8 4.5	9 4.3	10 46.6
Rotifera										
<i>Kellicottia longispina</i> (Kellicott)		4.95			6.40	2.55	10.12	2.65	10.15	
<i>Keratella cochlearis</i> (Gosse)		1.24			6.40	2.55		3.54	6.33	
unidentified aloricate forms					22.3	153.6	38.74	5.31	6.33	
Cladocera										
<i>Bosmina longirostris</i> (Müller)		0.03	0.34		0.16	0.03	0.05			
<i>Daphnia retrocurva</i> Forbes		0.18	0.69		0.82	0.21	0.16		0.04	
Copepoda										
<i>Diaptomus sicilis</i> Forbes		0.03	0.34		0.57	0.33	0.74	2.18	2.25	
<i>Ephschura lacustris</i> Forbes	0.24	0.03	0.43		0.57	0.64	0.26		0.11	
<i>E. nevadensis</i> Lilljeborg	0.16	0.31	0.60		0.41	0.21	0.16			
<i>Limnocalanus macrurus</i> Sars		0.03	0.17		0.41	0.94	0.16	0.33	0.50	
calanoid copepodids		0.52	2.16		3.03	5.70	4.38	26.64	19.95	
<i>Cyclops scutifer</i> Sars		0.06	0.95		0.90	0.30	0.40	3.35	9.67	
<i>Diaacyclops bicuspidatus thomasi</i> Forbes	0.24	0.90	5.52		7.61	0.70	1.80	0.44	0.23	
cyclopoid copepodids	0.41	2.47	7.60		13.01	3.27	7.34	3.78	4.00	
copepod nauplii	0.16	2.47	9.32		12.36	3.00	10.35	20.70	18.89	
Total										
Number of Species	1.21	7.04	28.12		39.85	15.33	25.80	57.42	55.64	
$\bar{d} \pm SE$	3 0.957 $\pm$ 0.070	10 1.155 $\pm$ 0.070	8 1.351 $\pm$ 0.112		11 1.544 $\pm$ 0.042	11 0.457 $\pm$ 0.027	10 0.827 $\pm$ 0.034	7 1.692 $\pm$ 0.024	9 1.612 $\pm$ 0.021	
e	0.67	0.30	0.38		0.36	0.18	0.20	0.57	0.44	

Table 18. Zooplankton abundance (numbers per litre), diversity ($\bar{d}$) and equitability (e) in Ya-Ya Lake, December, 1977.

Depth (m)	Station									
	1	2	3	4	5	6	7	8	9	10
Rotifera	0.3	0.3								
<i>Kellicottia longispina</i>				-	-	-	1.28	1.06	1.28	-
Cladocera										
<i>Daphnia middendorffiana</i> Fischer			not sampled		-	-	-	-	-	0.07
Copepoda										
<i>Diaptomus sicilis</i>				0.27	1.05	-	1.11	0.33	0.20	2.88
<i>Limnocalanus macrurus</i>				0.14	-	0.66	0.39	1.47	0.46	1.05
Nauplii				-	-	-	0.43	1.60	0.43	1.06
Ostracoda				-	-	-	-	-	-	0.07
Total	0	0		0.41	1.05	0.66	3.21	4.46	2.36	5.13
Number of species	0	0		2	1	1	3	3	3	4
$\bar{d} \pm SE$	-	-		0.553 $\pm$	0 $\pm$ 0	0 $\pm$ 0	0.989 $\pm$	0.944 $\pm$	0.830 $\pm$	0.720 $\pm$
e	-	-		0.133	1.00	1.00	0.043	0.055	0.084	0.048
				1.00	1.00	1.00	0.67	0.67	0.67	0.50

Table 19. Zooplankton abundance (numbers per litre), diversity ($\bar{d}$) and equitability (e) in Ya Ya Lake, July, 1978.

Station	1	2	3	4	5	6	7	8	9	10
Depth (m)	2.0	2.1	2.5	2.2	2.4	5.5	2.0	4.4	5.0	37.5
Copepoda										
<i>Diaicyclops bicuspidatus thomasi</i>	0.66	0.55	0.26	-	3.00	3.33	15.39	13.40	4.19	5.38
<i>Diaptomus sicilis</i>	-	-	-	0.30	0.41	0.48	6.22	4.76	3.41	5.87
<i>Limnocalanus macrurus</i>	0.16	0.16	-	1.27	0.68	0.48	2.62	0.30	0.26	3.91
immature cyclopoids	-	-	-	-	0.41	0.24	-	-	-	-
immature calanoids	-	-	-	0.74	3.27	0.71	3.60	2.98	1.05	0.98
Nauplii	-	0.23	0.26	6.62	33.98	4.53	4.58	8.04	3.14	9.29
Cladocera										
immature cladocerans	-	-	-	0.07	-	-	-	-	-	-
Rotifera										
<i>Kellicottia longispina</i>	-	-	-	-	-	-	-	0.30	-	-
Other	-	-	0.13	-	-	-	-	-	-	0.00
Total	0.82	0.94	0.65	9.0	41.75	9.77	32.41	29.48	12.05	25.43
Number of species	2	2	2	3	3	3	3	4	3	4
$\bar{d} \pm \text{SE}$	0.450 $\pm$	0.474 $\pm$	0.553 $\pm$	0.604 $\pm$	0.739 $\pm$	0.677 $\pm$	0.874 $\pm$	0.717 $\pm$	0.386 $\pm$	1.086 $\pm$
e	0.175	0.174	0.133	0.164	0.097	0.067	0.035	0.034	0.066	0.003
	1.00	1.00	1.00	0.67	0.67	0.67	0.67	0.50	0.33	0.75

most species existed as resting eggs and were therefore unavailable to the sampler. In the spring, most species were too young to be identifiable.

Most of the crustacean plankters found in Ya-Ya and the five survey lakes (Table 20) are common Arctic species and all are found elsewhere in the immediate study area (Reed, 1959; Slaney, 1975; McCart et al., 1976). *L. macrurus* is considered to be a relict species with marine affinities (Hutchinson, 1967:206), and is common in the nearby Mackenzie estuary (Slaney, 1975). The principal rotifers found are all common and widespread species (Edmondson, 1959).

Abundance, Diversity, and Equitability

In Figure 19, the abundances of the principal crustacean zooplankton species are shown in relation to suspended solids concentrations and Secchi transparency at each station. Diversity ($\bar{d}$) and equitability (e) values describing the zooplankton community at each station are also shown. Only the summer 1977 and spring 1978 data are presented: zooplankton numbers in the winter 1977 samples were too low to interpret with confidence (Table 18).

Relative to their numbers at other stations, several crustacean species were abundant at suspended solids concentrations of up to approximately 35 mg/L, but all crustacean species were absent, or nearly so, from stations at which suspended solids exceeded 100 mg/L.

Table 20. Zooplankton abundance (numbers per litre), diversity ($\bar{d}$) and equitability (e) in five survey lakes near Ya Ya Lake, late July - early August, 1977.

Lake	A	B	C	D	E
Rotifera					
<i>Asplanchna</i>	0.85	11.73			0.68
<i>Brachionus</i>	5.88				
<i>Filinia</i>	2.49				
<i>Kellicottia longispina</i>	20.13	25.50	25.63	24.38	144.22
<i>Keratella cochlearis</i>	155.36	319.50 ^a	6.40	5.25	74.20
<i>Ploesoma</i>		103.90 ^a	0.72		
<i>Polyarthra</i>		5.90			53.05
<i>Trichocerca</i>	0.85	13.70			
unidentified aloricate forms	15.10		54.46		4.24
Cladocera					
<i>Alona</i> sp.					0.34
<i>Bosmina longirostris</i>	0.06	2.62	0.07	0.55	6.05
<i>Chydorus sphaericus</i> (Müller)		0.49			
<i>Daphnia middendorffiana</i>				4.16	
<i>D. retrocurva</i>				0.11	
<i>Holopedium gibberum</i>			0.96		
Zaddach					
Copepoda					
<i>Diaptomus areticus</i>				0.87	
Marsh					
<i>D. pribilofensis</i>				7.54	
Juday and Muttowski	0.23		1.24		
<i>D. sicilis</i>					0.34
<i>Diaptomus</i> sp. (immature)					

(Continued)

Table 20. Continued.

Lake	A	B	C	D	E
<i>Epischura lacustris</i>	0.11 ^b		0.75		0.34
<i>Eurytemora</i>	0.11 ^b			0.11	0.95
<i>Limnocalanus macrurus</i>			0.56		
<i>Cyclops scutifer</i>			0.17		
<i>Diaicyclops bicuspidatus thomasi</i>			6.05	0.66	
calanoid copepodids	2.32	3.28	1.59	62.76	0.23
cyclopoid copepodids	0.11	0.66	9.56	35.21	0.23
nauplii	53.28	3.85	28.82	417.46	15.89
Harpacticoida copepodids	0.17				
Total	257.11	491.13	136.98	559.06	299.87
Number of species	13	8	11	9	10
$\bar{x} \pm SE$	$0.853 \pm 0.020 \quad 1.039 \pm 0.014 \quad 1.249 \pm 0.014 \quad 1.324 \pm 0.050 \quad 1.193 \pm 0.011$				
e	0.15	0.25	0.27	0.33	0.30

^a both *P. truncatum* (Levander) and *P. lenticulare* Herrick present

^b *E. composita* Keiser

Rotifer abundances tended to be low throughout the lake, except for an unidentified aloricate type that was common to abundant at Stations 5 to 7 in the summer 1977 samples. Diversity ($\bar{d}$) was not consistently related to either suspended solids concentrations or Secchi transparency (Figure 19). Species abundance and diversity would have shown the same relationships to shaken turbidity as they did to suspended solids, because shaken turbidity and suspended solids were highly correlated (p. 39).

In samples taken during the summer of 1977, there appeared to be little or no difference in equitability (e) between heavily-silted and lightly-silted stations. In the spring of 1978, however, e was apparently higher at heavily-silted than at lightly-silted stations (Figure 19, Table 19). At the low species numbers and diversities found in the Ya-Ya Lake zooplankton, e can take only a small number of fixed values when calculated from the table of Lloyd and Ghelardi (1964); consequently, e will be an unreliable and insensitive indicator of changes in such a simple community. In more complex communities, however, e can be a sensitive indicator of environmental stress (Weber, 1973).

High concentrations of suspended solids appear to be the most likely cause of the low zooplankton abundances and diversities found at stations in Region I. There was a slight but discernible flow of water at Stations 1, 2, and sometimes 3, from Tununuk Channel toward the Ya-Ya River (J. Den Beste, Aquatic Environments

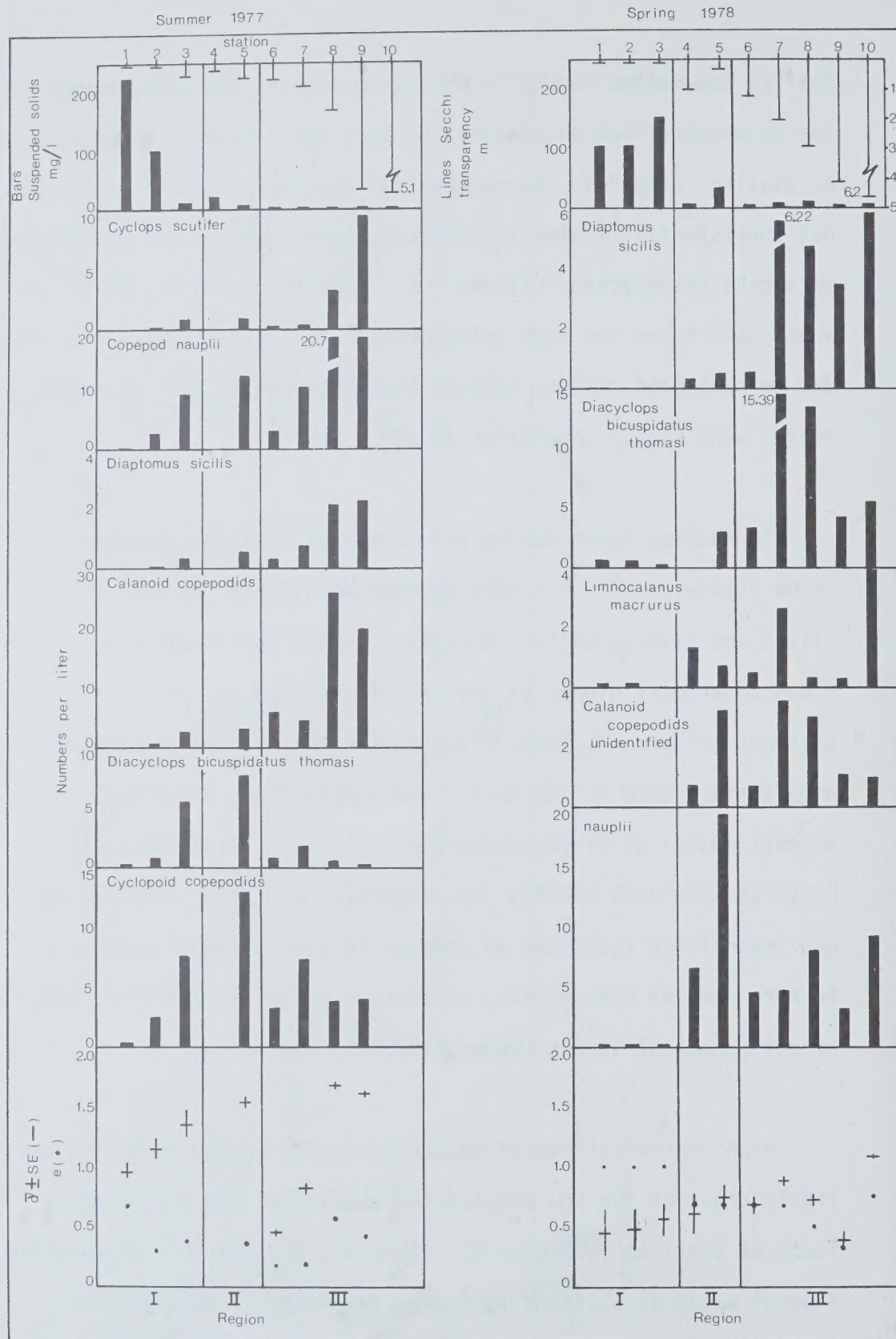


Figure 19. Suspended solids, transparency, equitability, diversity, and distribution of crustacean zooplankters, Ya-Ya Lake, 1977-78.

Limited, pers. comm.) which might have carried zooplankton away from these stations. It is unlikely, however, that this explanation can entirely account for the near-absence of zooplankton at these stations. Large, slow-flowing rivers comparable to the Mackenzie typically have a zooplankton community, although it is often greatly reduced at times of high turbidity (Hynes, 1970:98). Most of the silt particles were small enough to pass through the plankton net, so that there could have been little difference in the filtration efficiency of the net at silted and unsilted sites. Some of the lightly-silted stations were considerably deeper than the heavily-silted sites, but no species showed any tendency to be restricted to deep sites (Figure 19).

Organic matter, and fine inorganic matter not retained by glass fibre filters, kept Secchi transparency low at Stations 4 to 7, even though suspended solids were relatively low at those stations (Table 3, Figure 19). The fact that several species of zooplankters achieved high abundances at Stations 4 to 7 when Secchi transparencies were low suggests that if siltation is the cause of the paucity of zooplankton at Region I stations, it is the larger particles that affect the organisms. If so, Secchi transparency is likely to prove an inadequate measure of siltation if used to set siltation standards to protect zooplankton communities in waters like Ya-Ya Lake.

There appears to have been little study elsewhere of the

effects of siltation on zooplankton. The only experimental work on Arctic waters is that of de March et al. (1977), who found no change in the zooplankton abundance of a shallow tundra pond (maximum depth 30 cm) up to five weeks after silt was added at the rate of 500 mg/L. Probably because of rapid sedimentation, the maximum concentration of suspended solids reached was only 64 mg/L greater than the control (apparently 1 to 3 mg/L). Observations on some shallow lakes in semiarid regions also indicate that zooplankton can thrive in heavily-silted environments; in fact, the silt may be the basis of their food chain (Daborn, 1975).

On the other hand, there are observations that support the hypothesis that siltation can reduce plankton populations. Rawson (1956) noted that occasional high turbidity due to silt loading from the Slave River was associated with decreased plankton abundance at some Great Slave Lake stations. Benson and Cowell (1967), citing unpublished reports, stated that turbidity appeared to be the most important factor limiting plankton abundance in Missouri River reservoirs, and earlier work on the Missouri River proper (Berner, 1951) suggested that highly turbid water was responsible, at least in part, for low plankton abundance. Other studies suggesting that the plankton of large rivers can be reduced by high turbidity are cited by Hynes (1970:98). Slaney (1975:89) observed that copepods disappeared from several stations in the Mackenzie estuary when turbidity was high (540-680 ppm), but were again found when turbidity declined to 150 to 400 ppm.

The results of this and earlier studies suggest that the relationship between siltation and zooplankton abundance and diversity is not a simple one. Undoubtedly, species composition is an important factor. Particle size and type may be important, as the present results suggest. Future work might most profitably be directed toward experimental studies both in the field and in the laboratory to determine directly the effects of high silt loads on zooplankton communities.

Comparability of Survey Lakes

Although they also had relatively low turbidities and suspended sediment concentrations, four of the five survey lakes (A, B, D, and E) had zooplankton populations that differed markedly from that of comparable, lightly-silted stations in Region III of Ya-Ya Lake (compare Tables 17 and 20). There were differences in both species composition and abundance. Only Lake C appeared to resemble Region III of Ya-Ya Lake sufficiently with respect to the species composition and abundance of zooplankton to serve as an adequate control against which to measure the effects of siltation.

If control stations in Ya-Ya Lake had been unavailable, an apparently reasonable alternative might have been to use one or more of the nearby lakes as examples of relatively unsilted sites (e.g., Berger, 1977: Vol. II, P. 114, Item 8). The use of lakes A, B, D, or E as controls would, however, have led to erroneous conclusions about the effects of siltation on zooplankton in Ya-Ya

Lake, even though they resembled the silted areas in being shallow. The effects would have appeared to be far more pronounced than they actually were. Only Lake C would have served as a satisfactory control site, despite the fact that it was considerably deeper than the silted areas of Ya-Ya Lake. Lake C more closely resembled Ya-Ya Lake in area, however, than did the much smaller lakes A, B, D, and E. Clearly, the selection of one lake to act as a control for another entails a considerable risk and should be done only after careful study.

Vertical Migration

It had been intended to compare diel changes in vertical distribution of zooplankton at a heavily-silted and a lightly-silted site in Ya-Ya Lake, but zooplankton numbers at the highly-silted stations were too low to make a satisfactory comparison (Figure 18). Instead, vertical migration was studied at a lightly-silted site, Station 8, to determine if diel migration occurs in zooplankters subjected to a regime of 24 hour daylight.

Diel changes in solar illumination and vertical distribution of all zooplankton species abundant enough to appear consistently in the samples are shown in Figure 20, and tabulated in Table 21.

Hutchinson (1967:806) described typical vertical migratory behaviour of zooplankton as "... an upward movement in the late afternoon and evening, a nocturnal scattering downward, an upward

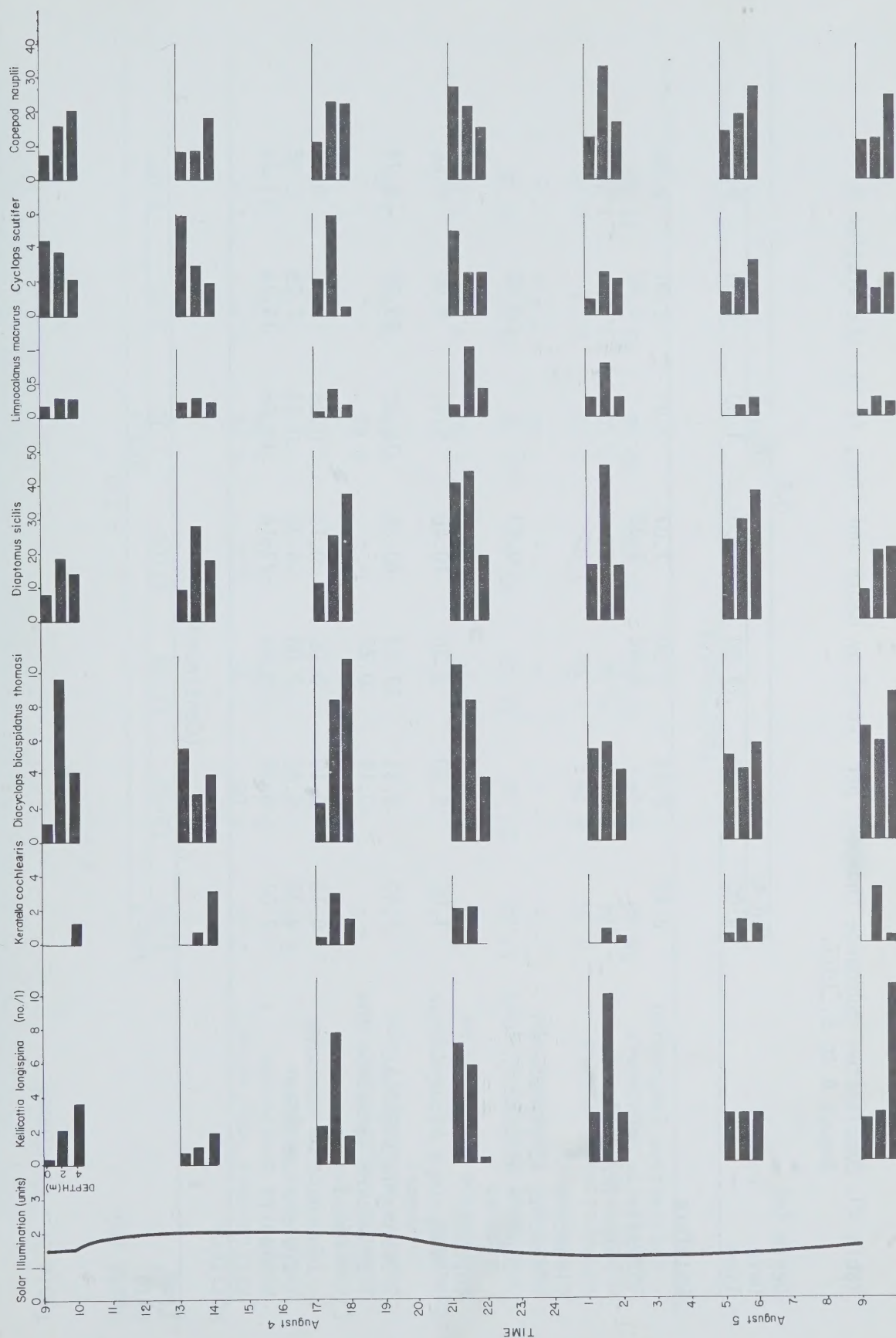


Figure 20. Solar illumination and vertical migration of zooplankton in Ya-Ya Lake, August 4-5, 1977.

Table 21. Zooplankton abundance (numbers per litre) by depth and time, Ya Ya Lake Station 8, August 4 to 5, 1977.

Depth (m)	0.5						
	Aug 4		Aug 5				
	9:00	13:00	17:00	21:00	1:00	5:00	9:00
Rotifera							
<i>Kellicottia longispina</i>	0.42	0.64	2.30	7.07	2.91	2.91	2.50
<i>Keratella cochlearis</i>	-	-	0.42	2.08	-	0.42	-
<i>Polarthra vulgaris</i>	-	-	-	-	-	-	0.83
Cladocera							
<i>Bosmina longirostris</i>	-	-	-	-	-	-	-
<i>Daphnia middendorffiana</i>	-	-	-	0.83	-	0.42	-
Copepoda							
<i>Diacyclops bicuspidatus thomasi</i>	1.06	5.50	2.30	10.40	5.41	4.99	6.66
<i>Diaptomus sicilis</i>	7.49	9.31	11.23	40.35	16.22	23.30	8.74
<i>Epischura lacustris</i> and <i>nevadensis</i>	-	0.16	0.22	-	-	-	-
<i>Limnocalanus macrurus</i>	0.13	0.19	0.06	0.13	0.26	-	0.06
<i>Cyclops scutifer</i>	4.38	5.82	2.08	4.90	0.83	1.25	2.50
nauplii	7.07	8.38	10.85	27.14	12.06	14.14	11.23

(Continued)

Table 21 . Continued.

Depth (m) Date Time	2.0					
	Aug 4		Aug 5			
	9:00	13:00	17:00	21:00	1:00	5:00 9:00
Rotifera						
<i>Kellicottia longispina</i>	2.08	1.06	7.90	5.82	9.98	2.91 2.91
<i>Keratella cochlearis</i>	-	0.64	2.91	2.08	0.83	1.25 3.14
<i>Polyarthra vulgaris</i>	0.42	-	-	-	-	- -
Cladocera						
<i>Bosmina longirostris</i>	-	-	-	-	0.42	- -
<i>Daphnia middendorffiana</i>	-	-	-	-	0.42	0.42 0.22
Copepoda						
<i>Diaicyclops bicuspidatus</i>	9.57	2.91	8.32	8.32	5.82	4.16 5.82
<i>Diaptomus sicilis</i>	17.89	27.68	25.38	43.68	45.76	29.54 20.38
<i>Epischura lacustris</i> and <i>nevadensis</i>	-	-	-	-	0.83	- -
<i>Limnocalanus macrurus</i>	0.26	0.26	0.38	1.02	0.77	0.13 0.26
<i>Cyclops scutifer</i>	3.74	2.91	5.82	2.50	2.50	2.08 1.47
nauplii	15.80	8.54	22.46	21.22	32.86	19.14 11.65

(Continued)

ascent just before dawn, and then a descent with a prolonged sojourn in deep water during the day." This typical behaviour was closely approached in Ya-Ya Lake by all the principal zooplankton species except *Keratella cochlearis*, which rose continuously from 0900 h to 2100 h (Figure 20), and *Limnocalanus macrurus*, which showed little change in vertical distribution during the study period. The low numbers of *K. cochlearis* and *L. macrurus* collected, however, make it impossible to interpret data describing them with confidence. The vertical migration patterns of *Kellicottia longispina* and *Cyclops scutifer* differed slightly from the typical case in that *Kellicottia* showed no evidence of a dawn upward movement and *C. scutifer* persisted at the surface until at least 1300 h.

The diel light regime is considered to be the principal factor governing vertical migration in zooplankton (Hutchinson 1967:806). In Ya-Ya Lake, zooplankters exhibit a typical diel migration under a regime of 24 h daylight in which minimum daily illumination is more than 60% of the maximum (Figure 20), showing that darkness is not required to elicit the typical behaviour.

Conclusions

1. Most zooplankton species in Ya-Ya Lake and the survey lakes are common and widespread species in the Arctic.
2. Most species of zooplankton found in summer in Ya-Ya

Lake were absent from winter and spring samples, probably because most populations overwinter as resting stages and are not mature enough to be identifiable to species in spring.

3. Abundance of crustacean zooplankton was reduced at stations in Ya-Ya Lake with high concentrations of suspended solids.

4. The diversity index ($\bar{d}$) was insensitive to changes in the zooplankton community of Ya-Ya Lake, but an analysis of the abundances of individual species provided clear evidence of environmental differences among stations.

5. The equitability index (e) as estimated from the table of Lloyd and Ghelardi (1964) is not a reliable indicator of changes in zooplankton communities having few individuals and species.

6. Secchi transparency was not a reliable indicator of the effect of siltation on Ya-Ya Lake zooplankton.

7. On the basis of zooplankton composition and abundance, only Lake C, of the five survey lakes, could serve as a satisfactory control against which the effects of siltation on Ya-Ya Lake zooplankton could be measured.

8. Ya-Ya Lake zooplankton exhibited typical vertical migration patterns under a regime of 24 h daylight, indicating that darkness is not required to elicit vertical migratory behaviour.

ZOOBENTHOS

By

P.T.P. Tsui, Ph.D.

ZOOBENTHOS

Introduction

The objectives of this portion of the study were:

- 1) to compare the spatial distribution and relative abundance of dominant zoobenthos at silted and control stations of Ya-Ya Lake;
- 2) to examine certain zoobenthic community responses to siltation; e.g., species diversity, equitability, taxonomic diversity, standing crop;
- 3) to determine the practicality of using "macroinvertebrate standards" as a definitive criterion for assessing ecological damage (Berger, 1977).

Methods

In Ya-Ya Lake, benthic invertebrate samples were taken in the vicinity of the 10 permanent stations indicated in Figure 1. At each permanent station, a transect was established across the lake perpendicular to the shoreline and samples were taken at 2 to 5 points, approximately equidistant, along the transect, the number of sampling points depending on the width of the lake. The sampling points were positioned so that they sampled the deeper

portions of the lake and the sublittoral zone but did not include the shallow littoral subject to ice-scour. At each sampling point along the transect, triplicate grab samples were taken with a Burton-Flannagan Ekman dredge. This device samples an area of 0.023 m^2 .

In the 5 unnamed survey lakes (A, B, C, D, and E), triplicate Ekman samples were taken at three sampling points along a half transect in each lake. The sampling was performed during the summer of 1977.

Sampling effort during the study is summarized in Table 22. A total of 234 grab samples was taken, 114 during the summer sampling period in 1977 and 120 during the spring sampling in 1978.

In the field, samples were sieved through a U.S. Standard No. 30 sieve and then preserved in a 10% formalin solution containing 100 mg/L of Rose Bengal, a vital stain, to facilitate sorting of benthic organisms. During this initial treatment, notes were made of the characteristics of the substrate taken in the sample--e.g., mud, sand, detritus, moss.

In AEL's Calgary laboratory, the samples were sieved a second time using the U.S. Standard No. 30 sieve, then spread out in Petri dishes or enamelled pans so that organisms could be separated from debris. Organisms were initially separated by

Table 22. Summary of benthic invertebrate sampling effort, Ya-Ya Lake, 1977 and 1978.

Station	Summer, 1977		Spring, 1978		Total No. of Grabs
	Number of Sampling Points	No. of Grabs	Number of Sampling Points	No. of Grabs	
1	5	15	5	15	30
2	3	9	3	9	18
3	5	15	5	15	30
4	3	9	3	9	18
5	3	9	3	9	18
6	5	15	5	15	30
7	2	6	3	9	15
8	4	12	5	15	27
9	3	9	3	9	18
10	5	15	5	15	30
Totals	38	114	40	120	234

major group (family, order, or class) and later identified to the lowest possible taxon (genus or species).

The major taxonomic references used included Allen and Edmunds (1961a, 1961b, 1965), Jensen (1966), Jewett (1959), Needham et al. (1935), Pennak (1953), Ricker (1943, 1964), Usinger (1963), and Ward and Whipple (1959). The Chironomidae were identified according to a provisional key by Hamilton and Saether (Unpublished key, Environment Canada, Freshwater Institute, Winnipeg).

Shannon-Weaver species diversity indices and MacArthur equitability indices were computed according to the methods previously described for phytoplankton.

In addition to the samples from Ya-Ya Lake, benthic invertebrate samples were taken from five other lakes (A, B, C, D, and E) in the same vicinity (Figure 1). Triplicate grab samples were taken from three sampling points along a half transect in each lake during the summer sampling period in 1977. The samples were preserved and processed as previously described for the Ya-Ya Lake samples.

Results and Discussion

Ya-Ya Lake

The Benthic Environment

Brunskill et al. (1975) indicated that sub-Arctic and Arctic rivers of the Mackenzie and Porcupine watersheds transport relatively large amounts of suspended sediments per unit watershed area, compared to other major North American rivers. The large amount of silt carried into the southern end of the Ya-Ya Lake system by the Mackenzie River water has a profound effect on the substrate characteristics of Ya-Ya Lake. Table 23 summarizes the substrate type(s) found at the 10 sampling stations. The predominantly brown mud and sandy substrates found at Stations 1 through 4 probably delineate the area of the lake basin most influenced by river water. The presence of aquatic mosses at Stations 7 through 9 indicates the absence of the river influence at these areas. Lewis (1973) has pointed out that growth of aquatic moss is inhibited in silty water because of the unstable substrates and the reduction of light penetration.

Distribution and Relative Abundance of Major Groups

Table 24 compares the percentage composition of major groups (mainly Orders) of zoobenthos in samples from three regions of Ya-Ya Lake. The data indicate that in both 1977 and 1978 and in each of the three regions of the lake, amphipods were the single most abundant group, ranging from 35.6% to 72.5% of the total

Table 23. Substrate type(s) at the Ya-Ya Lake benthic sampling stations.

Station	Substrate Type(s)
1	brown mud
2	brown mud
3	brown mud > sand
4	brown mud > sand
5	brown mud > sand > detritus
6	brown mud > detritus
7	brown mud > detritus > moss
8	moss > brown mud > detritus
9	moss > brown mud
10	brown mud > detritus

Table 24. Percentage compositions of main groups in the zoobenthos of three regions of Ya-Ya Lake during the summers of 1977 and 1978.

Year	Major Taxon	Percentage Composition			Means
		Region I (Sta. 1-3)	Region II (Sta. 4-5)	Region III (Sta. 6-10)	
1977	Oligochaeta	27.6	1.9	16.9	15.5
	Nematoda	1.0	3.4	1.8	2.1
	Isopoda	0	0.2	0.7	0.5
	Amphipoda	40.3	58.6	35.6	44.8
	Mysidacea	0	0.5	0.5	0.3
	Ostracoda	0	0	0	<0.1
	Trichoptera	0	0	0.2	0.1
	Diptera	8.2	4.4	20.4	11.0
	Mollusca	22.9	30.8	23.8	25.8
1978	Oligochaeta	6.9	1.3	8.7	5.6
	Nematoda	0.2	0.2	0.4	0.3
	Isopoda	0	0.6	1.7	0.8
	Amphipoda	72.5	67.0	45.0	61.5
	Mysidacea	0.1	1.3	2.3	1.2
	Ostracoda	1.1	0	0	0.3
	Ephemeroptera	0.2	0	0	0.1
	Trichoptera	0	0	0.4	0.1
	Diptera	11.3	2.7	22.1	12.0
	Mollusca	7.6	26.8	19.3	17.9
1977/78 Combined					
	Oligochaeta	17.2	1.6	12.8	10.5
	Nematoda	0.6	1.8	1.1	1.2
	Isopoda	0.0	0.4	1.2	0.6

Continued

Table 24. Continued.

Year	Major Taxon	Percentage Composition			Means
		Region I (Sta. 1-3)	Region II (Sta. 4-5)	Region III (Sta. 6-10)	
	Amphipoda	56.4	62.8	40.3	53.1
	Mysidacea	<0.1	0.9	1.4	0.7
	Ostracoda	0.5	0.0	<0.1	0.2
	Ephemeroptera	0.1	0.0	0.0	<0.1
	Trichoptera	0.0	0.0	0.3	0.1
	Diptera	9.7	3.5	21.2	11.5
	Mollusca	15.2	28.8	21.5	21.8

samples within regions. Other abundant groups which can be considered to be dominants (i.e., exceed 10% of the total benthic fauna in samples from one or more regions) include the Oligochaeta, the Diptera, and the Mollusca.

Of the dominant groups, the Amphipoda were by far the most abundant, overall 2.4 times as abundant as the next most numerous group, the Mollusca. Amphipods were relatively most abundant in Region II in 1977 and Region I in 1978. In both years, they were relatively least abundant in Region III. There was a striking difference between the two years in the relative abundance of amphipods which, in all three regions, constituted a larger proportion of catches in 1978 than in 1977. This may have been due to differences in the sampling period, which was earlier in 1978 (July) than in 1977 (July/August), so that the 1978 samples were taken at a time in the life cycle when the amphipods were more susceptible to capture.

In both years, the Mollusca constituted the greatest proportion of the catch in Region II, were relatively next most abundant in Region III, and least abundant in Region I. The Diptera, third in order of overall relative abundance, exhibited the same pattern in 1977 and 1978. They were proportionately most abundant in Region III, least abundant in Region II, and intermediate in Region I. Like the Diptera, the Oligochaeta had their lowest relative abundance in Region II and their greatest in Regions I

and II, though their importance in the latter varied between years.

Several groups of minor overall importance have distributions which suggest that they may be responding negatively to heavy sediment loadings. These groups, which include the Isopoda, Mysidacea and Trichoptera are absent or nearly so from Region I and reach their greatest relative abundance in Region III.

Of the dominant groups among the zoobenthos of Ya-Ya Lake, probably the best known in terms of both their taxonomy and their ecology are the Diptera, especially the Chironomidae. For this reason, it is likely that they will prove most useful in assessing the impact on lake ecosystems of sedimentation resulting from human activity. It should be noted, however, that the group includes many species, each with its own habitat preferences and that, at the group level, there is no simple relationship between relative abundance within a region and the turbidity and suspended sediment characteristics of that region. While the group was relatively most abundant in Region III, the clearest of the regions, it was still well represented in Region I, the most turbid. Obviously, a more detailed taxonomic analysis is required.

Species Composition and Distribution

Data describing the species composition and densities of benthic invertebrates in samples from Ya-Ya Lake are presented in Tables 25 (1977 samples) and 26 (1978 samples).

Table 25. Species composition and density (number/m²) of zoobenthos in Ya-Ya lake, July 29 - August 5, 1977.

Taxon	Station									
	1	2	3	4	5	6	7	8	9	10
Oligochaeta	458	135	217	24	14	32	435	438	406	107
Nematoda	-	10	20	39	29	52	29	35	19	12
Isopoda	-	-	-	-	5	-	29	11	5	17
<i>Saduria entomon</i>	-	-	-	-	-	-	-	-	-	-
Amphipoda	-	-	-	-	-	-	36	663	377	3
<i>Gammarus lacustris</i>	-	-	-	-	-	-	384	7	1069	310
<i>Pontoporeia affinis</i>	194	560	429	459	696	128	-	-	-	-
Mysidacea	-	-	-	5	5	-	14	11	5	12
<i>Mysis relicta</i>	-	-	-	-	-	-	-	-	-	-
Ostracoda	-	-	-	-	-	3	-	-	-	-
Trichoptera	-	-	-	-	-	-	-	-	14	-
<i>Grensia praeterita</i>	-	-	-	-	-	-	-	-	-	-
Diptera	-	-	-	-	-	-	7	-	-	-
<i>Polypedilum</i> sp.	-	-	-	-	-	-	29	-	92	9
<i>Protonypus</i> sp. B	-	-	-	-	-	-	22	11	43	-
<i>Tanytarsus</i> sp.	-	-	-	-	-	-	7	-	-	-
<i>Microtendipes</i> sp.	-	-	-	-	-	-	14	283	599	-
<i>Rheotanytarsus</i> sp.	-	-	-	-	-	-	7	-	-	-
<i>Paracladopelma</i> sp.	-	-	-	-	-	-	-	-	-	-
<i>Bezzia</i> sp.	3	5	-	-	-	-	-	-	-	-

(Continued)

Table 25. Continued.

Taxon	Station									
	1	2	3	4	5	6	7	8	9	10
<i>Procladius</i> sp.	72	101	17	24	5	3	15	29	10	3
<i>Cryptochironomus</i> sp. A	3	19	3	-	-	-	-	-	-	-
<i>Cryptochironomus</i> sp. B	-	-	6	14	29	38	7	-	-	-
<i>Chironomus</i> cf. <i>atritibia</i>	6	-	-	-	-	-	-	-	-	-
<i>Trichocladius</i> sp.	-	-	-	-	-	-	-	-	5	-
<i>Monodiamesa</i> sp.	-	-	-	-	5	-	7	7	19	-
<i>Monodiamesa tuberculata</i>	-	5	-	-	-	-	-	-	34	-
<i>Zalutschia lingulata</i>	-	-	-	-	-	-	-	-	-	23
<i>Stictochironomus</i> cf. <i>rosenschoeldi</i>	-	-	-	5	-	-	-	4	-	-
<i>Dicrotendipes</i> sp.	-	-	-	5	-	-	7	80	101	-
<i>Heterotrissocladius</i> sp.	-	-	-	-	-	3	-	-	-	-
<i>Orthocladius</i> sp.	-	-	-	-	-	6	-	11	24	-
<i>Conchopelopia</i> sp.	-	-	-	-	-	-	-	4	-	-
<i>Smittia</i> sp.	-	-	-	-	-	-	-	11	39	-
<i>Thienemannimyia</i> grp. sp.	-	-	-	-	-	-	-	4	-	-
	-	-	-	-	-	-	-	91	-	-
Mollusca										
<i>Pisidium conventus</i>	67	97	-	-	-	84	138	87	246	35
<i>Pisidium casertanum</i>	-	58	-	-	-	-	-	159	43	-
<i>Pisidium compressum</i>	-	5	-	-	-	-	-	-	-	-
<i>Pisidium ventricosum</i> (<i>rotundatum</i> form)	-	5	-	-	-	-	-	-	-	-
<i>Pisidium subtruncatum</i>	-	-	113	111	184	93	36	-	53	-
<i>Pisidium lilljeborgi</i>	-	-	-	-	-	-	-	4	-	-
<i>Pisidium idahoense</i>	-	-	-	-	-	-	-	14	-	-

(Continued)

Table 25. Continued.

Taxon	Station									
	1	2	3	4	5	6	7	8	9	10
<i>Pisidium</i> spp.	14	266	26	111	111	46	80	72	585	14
<i>Sphaerium nitidum</i>	-	-	17	-	-	6	-	18	-	-
<i>Valvata lewisi</i>	-	5	-	-	24	38	-	98	34	-
<i>Valvata</i> sp.	-	-	-	-	-	-	7	-	-	-
Total Number of Taxa	8	13	9	10	11	13	20	24	22	11
Density (no./m ²)	817	1271	848	797	1107	532	1310	2142	3813	545
Shannon-Weaver Species Diversity Index ($\bar{d}$)	1.78	2.41	1.98	2.01	1.89	3.04	2.81	3.16	3.16	2.08
Equitability (e)	0.63	0.54	0.56	0.50	0.36	0.92	0.55	0.54	0.59	0.46

Table 26. Species composition and density (number/m²) of zoobenthos in Ya-Ya lake, August, 1978.

Taxon	Station									
	1	2	3	4	5	6	7	8	9	10
Oligochaeta	203	29	35	24	5	38	101	101	145	122
Nematoda	6	-	3	-	5	9	10	-	5	-
Ostracoda	32	-	9	-	-	-	-	-	-	-
Isopoda										
<i>Saduria entomon</i>	-	-	-	14	-	-	-	-	72	17
Mysidacea										
<i>Mysis relicta</i>	-	-	3	14	14	14	14	9	5	3
Amphipoda										
<i>Gammarus lacustris</i>	-	-	-	-	-	-	97	357	396	-
<i>Pontoporeia affinis</i>	678	908	1197	903	570	145	792	168	406	52
Ephemeroptera										
<i>Baetis</i> sp.	10	-	-	-	-	-	-	-	-	-
Trichoptera										
<i>Grensia praeterita</i>	-	-	-	-	-	-	-	-	19	3
Diptera										
<i>Chironomus</i> cf.										
<i>atritibia</i>	-	-	-	-	5	-	-	-	-	-
<i>Cladytanytarsus</i> sp.	-	-	-	-	-	-	-	-	5	-
<i>Conchopelopia</i> sp.	-	-	-	-	-	-	140	12	101	-

(Continued)

Table 26. Continued.

Taxon	Station									
	1	2	3	4	5	6	7	8	9	10
<i>Cryptochironomus</i> sp. A	14	-	6	10	-	-	-	-	-	-
<i>Cryptochironomus</i> sp. B	67	10	20	-	-	-	-	-	-	-
<i>Cryptochironomus</i> nr. <i>defectus</i>	10	-	-	-	-	-	-	-	-	-
<i>Endochironomus</i> sp.	-	-	-	-	5	-	-	-	-	-
<i>Heterotrissocladius</i> sp.	23	19	23	10	-	32	5	-	-	-
<i>Monodiamesa</i> sp.	-	-	-	-	-	3	19	12	48	6
<i>Polypedilum</i> sp.	84	24	-	-	-	3	-	3	-	-
<i>Procladius</i> sp.	3	-	58	10	14	5	77	9	10	-
<i>Procladius</i> sp. B	10	-	-	-	-	-	-	-	-	-
<i>Protanypus</i> sp.	10	-	-	-	-	-	-	-	-	-
<i>Psectrocladius psilopterus</i>	43	5	14	-	-	-	5	61	155	-
<i>Stictochironomus</i> cf. <i>rosenschoeldi</i>	-	-	-	-	-	301	10	-	-	6
<i>Tanytarsus</i> sp.	-	-	3	-	-	14	106	29	4	-
<i>Zalutschia lingulata</i>	-	-	-	-	-	3	-	-	-	-
<i>Bezzia</i> sp.	-	-	-	5	-	-	-	-	-	-
Mollusca	-	-	9	-	10	-	19	-	14	-
<i>Pisidium casertanum</i>	12	-	3	-	-	17	-	35	53	64
<i>Pisidium conventus</i>	-	-	-	-	-	-	-	12	-	-
<i>Pisidium idahoense</i>	10	-	-	-	-	12	34	-	14	-
<i>Pisidium lilljeborgi</i>	12	-	29	116	100	12	-	14	164	32
<i>Pisidium subtruncatum</i>	120	-	38	58	121	17	87	14	29	120
<i>Pisidium ventricosum</i> (<i>rotundatum</i> form)	-	-	-	-	-	-	-	-	-	-

(Continued)

Table 26. Continued.

Taxon	Station									
	1	2	3	4	5	6	7	8	9	10
<i>Pisidium</i> spp.	20	-	38	58	121	17	87	14	29	20
<i>Sphaerium nitidum</i>	-	-	-	-	-	9	10	17	24	-
<i>Valvata lewisii</i>	-	-	-	-	5	-	-	-	48	-
Total Number of Taxa	18	6	15	10	11	17	16	14	20	10
Density (no./m ²)	1237	995	1450	1164	859	638	1526	853	1756	325
Shannon-Weaver Species Diversity Index ($\bar{d}$)	2.34	0.61	1.23	1.31	1.65	2.57	2.58	2.71	3.37	2.55
Equitability (e)	0.39	0.33	0.20	0.30	0.36	0.47	0.50	0.60	0.75	0.80

A total of 42 taxa (mostly species) were identified in samples from the study area. The spatial distributions of these taxa in relation to suspended sediment and turbidity levels in Ya-Ya Lake are shown in Figure 21. For purposes of this discussion, the study area in Ya-Ya Lake has been divided into three regions which correspond to the degree of siltation during the open water season. These have been previously described in the section on Water Quality. Region I, an area of heavy siltation, includes Stations 1 through 3; Region II, an area of moderate siltation, includes Stations 4 and 5; and Region III, an area of low siltation, includes Stations 6 through 10.

Thirteen taxa occurred in all three regions including the Oligochaeta and Nematoda (the Vermes or worm-like organisms); the amphipod *Pontoporeia affinis*; the mysid *Mysis relicta*; six dipteran species (*Bezzia* sp., *Procladius* sp., *Cryptochironomus* sp. B, *Monodiamesa* sp., *Stictochironomus* cf. *rosenschoeldi*, and *Zalutschia lingulata*); two species of sphaeriid clams (*Pisidium casertanum* and *P. subtruncatum*); and a gastropod (*Valvata lewesi*). Despite their wide distribution, however, these taxa did differ in the details of their individual distributions. Among the 10 most abundant of the 13 taxa (Figure 22), those which can be considered to be dominants within at least one region of the lake, only five can be considered to be polylichtophilous (i.e., occurring at moderate to high densities over a wide range of turbidities). These are the Oligochaeta, Nematoda, *Pontoporeia*

affinis, *Procladius* sp., and *Cryptochironomus* sp. B. The first two taxa are, in fact, orders and may include many species, each individually adapted to a narrower range of sediment conditions. It is not surprising that at the ordinal level of taxonomic distinction, they are widely distributed within Ya-Ya Lake. The other three taxa are individual species or, in the case of *Procladius* sp., one or two species of closely related and similarly adapted organisms.

The other five dominant taxa all appear to be mesolichtophilous (i.e., characteristic of waters which are generally clear but occasionally clouded). Though they occur over a full range of suspended sediment conditions, they each reach their greatest mean densities in Region III, the clear end of the lake.

Only four taxa were found exclusively in Region I (Figure 21): a baetid mayfly (*Baetis* sp.), two species of midge (*Cryptochironomus* nr *defectus* and *Psectrocladius psilopterus* type), and one species of sphaeriid clam (*Pisidium compressum*). *Cryptochironomus* sp. A, and *Chironomus atritibia* were found in Region I and II only, whereas *Endochironomus* sp. was found only in Region II (Figure 21).

The common estuarine isopod *Saduria entomon* was found in both Regions II and III but had a greater density in the latter (Tables 25 and 26).

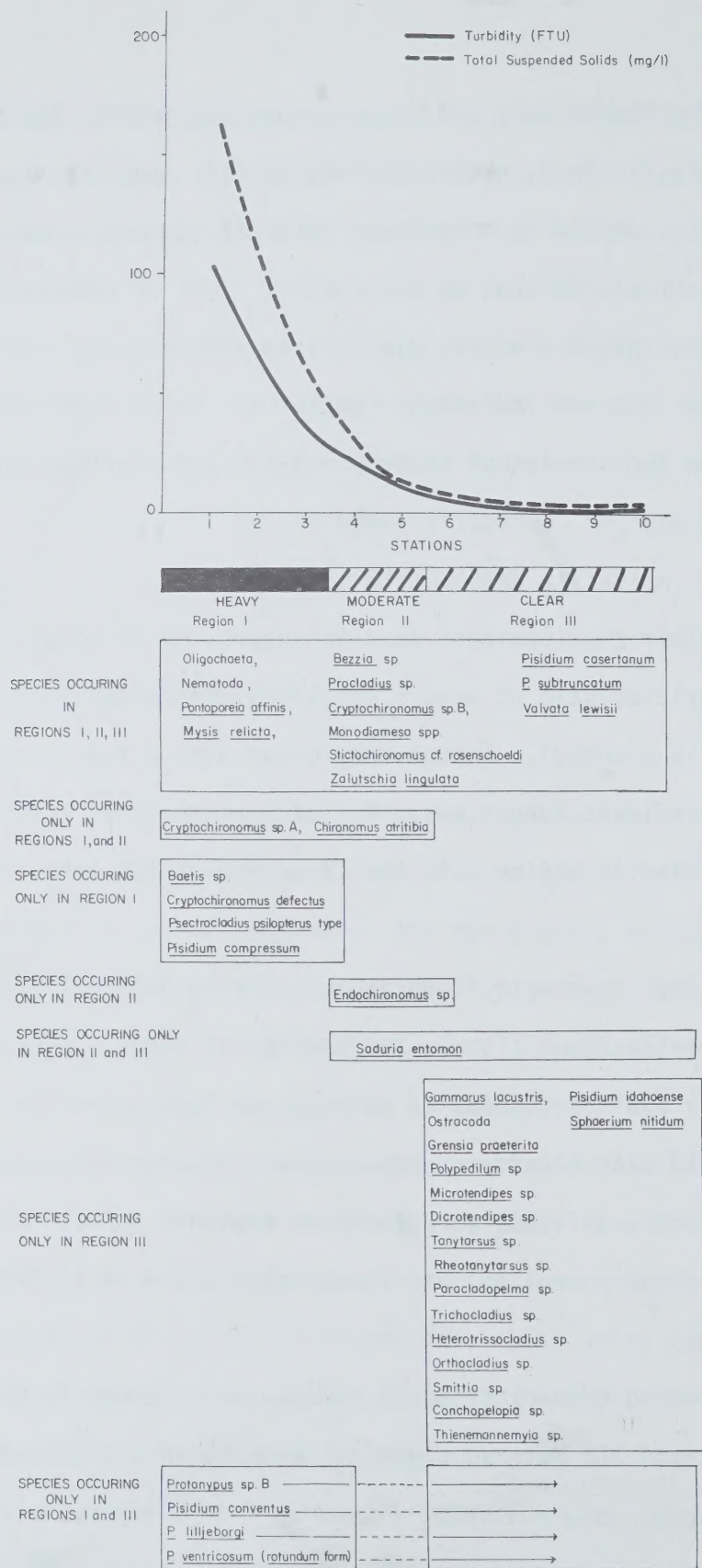


Figure 21. Distribution of zoobenthos in relation to mean total suspended solids (mg/L) and mean turbidity (FTU) levels in Ya-Ya Lake, N.W.T., during the open-water season, July-August 1977 and July 1978.

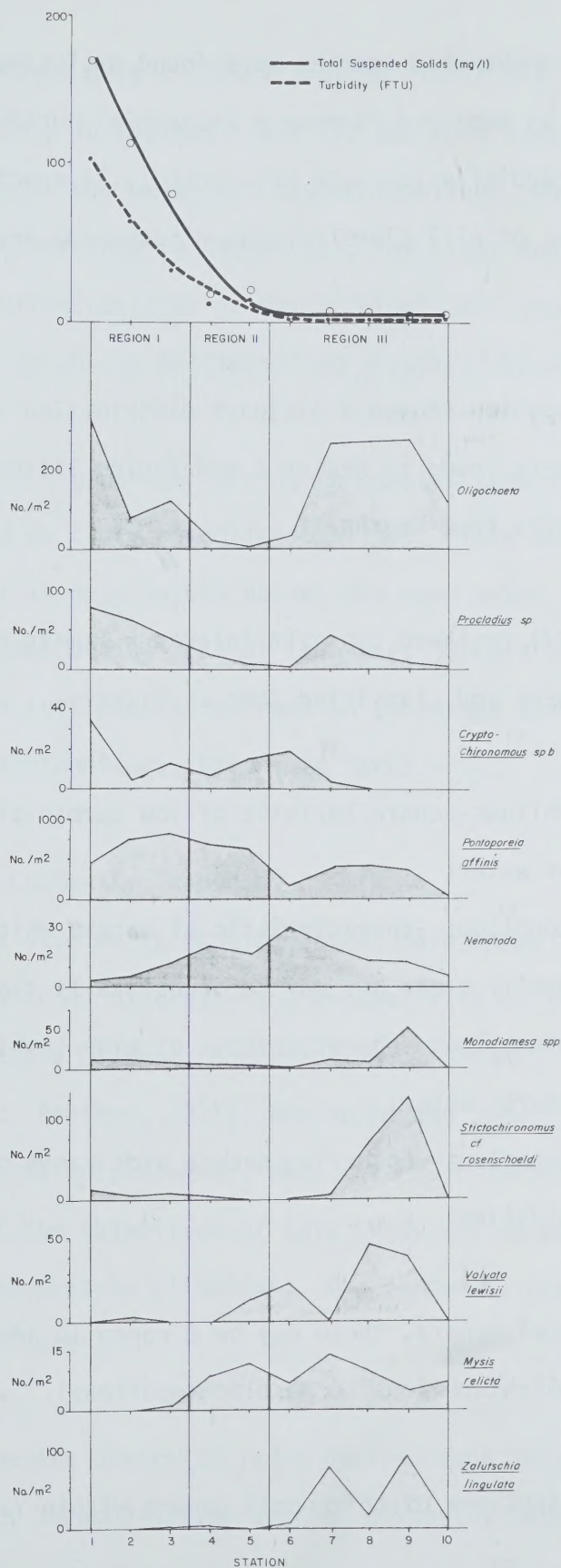


Figure 22. Distribution and abundance of certain dominant zoobenthos in relation to mean total suspended solid and mean turbidity levels in Ya-Ya Lake, N.W.T., July-August 1977 and July 1978. Taxa are arranged in order of decreasing representation in Region I.

Seventeen zoobenthic species were found exclusively in Region III including an amphipod (*Gammarus lacustris*), unidentified ostracods, a caddisfly (*Grensia praeterita*), 12 species of midges, and two species of pill clams (*Pisidium idahoense* and *Sphaerium nitidum*).

Several species showed a disjunct distribution in the lake in that they were found in Region I and Region III only and were absent in samples from Region II.

Beck (1977) reviewed the silt tolerance limits of various chironomid genera and classified them as either:

Eulichtophilous--characteristic of low turbidities and clear water;

Mesolichtophilous--characteristic of waters which are generally clear but may be occasionally clouded;

Oligolichtophilous--characteristic of high turbidities and murky water;

Polylichtophilous--occurring over a wide range of turbidities.

Within individual genera, there may be a range in adaptation (e.g., from Eulichtophilous to Mesolichtophilous).

The distributions of chironomid genera within Ya-Ya Lake

generally reflect Beck's classification (Table 27). The genera which occur only in Regions I and II, the more turbid areas of the lake, range from meso- to polylichtophilous, while most of those which occur only in Region III, the clear end of the lake, are either eulichtophilous or mesolichtophilous though there are a few genera which can be classified as polylichtophilous.

Most of the genera occurring in samples from Ya-Ya Lake can be classified as truly oligolichtophilous. This may be because even Region I is only turbid during the open water season and is relatively clear during most of the year. Conditions may not, therefore, be sufficiently extreme to encourage the development of an oligolichtophilous chironomid fauna.

Zoobenthic Community Response

Previous studies in running waters have shown that sedimentation reduces the species diversity and productivity of the zoobenthic community (Chutter, 1969; Buscemi, 1966; Gammon, 1970; Luedtke et al., 1976; Prather, 1971; Rosenberg and Snow, 1975). These conclusions have not, however, been tested in lentic conditions. Hence, one of the objectives of this study was to evaluate community responses to siltation. The community parameters chosen for evaluation are:

- 1) a species diversity index derived from information theory; e.g., Shannon-Weaver Species Diversity Index (Shannon and

Table 27. Classification of certain Ya-Ya Lake chironomid genera based on their known silt tolerance limits as reviewed by Beck (1977).

Occurrence in Region(s)	Genus	Eulichtophilous	Mesolichtophilous	Polylichtophilous
I, II, III	<i>Stictochironomus</i>	+	+	+
	<i>Cryptochironomus</i>		+	+
	<i>Procladius</i>		+	
I, II only	<i>Chironomus</i>		+	+
I only	<i>Psectrocladius</i>		+	+
II only	<i>Endochironomus</i>		+	+
III only	<i>Paracladopelma</i>	+		
	<i>Thienemannimyia</i>	+		
	<i>Microtendipes</i>		+	
	<i>Tanytarsus</i>		+	
	<i>Heterotrissocladius</i>		+	
	<i>Smittia</i>		+	
	<i>Conchopelopia</i>		+	
	<i>Orthocladius</i>	+	+	
	<i>Polypedilum</i>	+	+	+
	<i>Dicrotendipes</i>	+	+	+
	<i>Rheotanytarsus</i>	+	+	+

Weaver, 1949);

2) a community evenness index; e.g., MacArthur's equitability index (MacArthur, 1957; Lloyd and Ghelardi, 1964);

3) taxonomic diversity (total number of taxa); and

4) standing crop expressed as number of zoobenthos/m².

Table 28 summarizes the mean values of these parameters for the three regions of Ya-Ya Lake. There were no significant differences between Regions I and II in the values of the parameters and the data for the two regions were therefore combined. When, however, the combined data for Regions I and II were compared with those for Region III, species diversity, equitability, and taxonomic diversity were all found to differ significantly. The exception was standing crop which, though higher in Region III (27% more than in the combined sample), did not differ significantly between regions.

While these data certainly suggest that within Ya-Ya Lake, the zoobenthic community is responding negatively to sedimentation, other studies in the area have been unable to establish that similar relationships hold among lakes. Regression analyses performed for data from Ya-Ya and 23 other Mackenzie Delta lakes (McCart et al., 1976) failed to establish any significant negative

Table 28. Comparison of certain zoobenthic community parameters in the silted and clear regions of Ya-Ya Lake, N. W. T.

	Silted			Clear
	Region I	Region II	Region I & II	Region III
Total suspended solids (mg/L)	119.9	17.6	80.9	5.1
Turbidity (FTU)	69.3	14.5	48.4	3.8
Mean Species Diversity (d)	1.73(± 0.28)	1.69(± 0.15)	1.71(± 0.17)*	2.81(± 0.12)*
Mean Equitability (e)	0.44(± 0.07)	0.38(± 0.04)	0.42(± 0.04)*	0.62(± 0.05)*
Mean Taxonomic Diversity	11.5 (± 1.87)	10.5 (± 0.29)	11.1 (± 1.1)*	16.8 (± 1.5)*
Mean Standing Crop (no./m ²)	1103 (±104)	982 (±90)	1055 (±71)	1344 (±334)

* t values differ significantly at 95% probability level, df = 18.

correlations between the same community parameters and total suspended sediment concentrations or turbidity.

Survey Lakes

Zoobenthos from five relatively clear lakes (A, B, C, D, E) were studied with the intention of comparing them with the clear region of Ya-Ya Lake (Region III). During the summer of 1977, triplicate Ekman dredge samples were taken at three sampling points along a half transect in each lake. The results are presented in Table 29.

The coefficient of community (Patalas, 1971) was used to determine the degree of similarity in the zoobenthic species compositions between the survey lakes and that of Ya-Ya Lake Region III (Table 30). The coefficient of community is a measure of the percentage of species common to two communities:

$$CC = \frac{100 \cdot c}{a+b-c}$$

where: a = the number of species in the first community

b = the number of species in the second community

c = the number of species common to both communities

The coefficient equals 100 when two communities are composed of identical species, and equals 0 when two communities have entirely different species.

Table 29. Species composition and density (No./m²) of zoobenthos from five survey lakes (A,B,C,D,E) in the vicinity of Ya-Ya Lake, July 29 - August 5, 1977.

Taxon	A	(%)	B	(%)	C	(%)	D	(%)	E	(%)
Oligochaeta	2507	(44.82)	256	(17.69)	111	(27.34)	126	(4.05)	208	(8.46)
Nematoda	19	(0.34)	63	(4.35)	5	(1.23)	15	(0.48)	-	-
Hirudinea	24	(0.43)	10	(0.69)	-	-	-	-	10	(0.41)
<i>Placobdella</i> sp.										
Amphipoda	130	(2.32)	82	(5.67)	-	-	116	(3.73)	386	(15.69)
<i>Gammarus lacustris</i>	-	-	-	-	-	-	77	-	19	-
<i>Hyalella asteca</i>	-	-	-	-	-	-	-	-	367	-
<i>Pontoporeia affinis</i>	-	-	-	-	217	(53.45)	39	-	-	-
Mysidacea	-	-	-	-	-	-	10	(0.32)	-	-
<i>Mysis relicta</i>										
Conchostraca	-	-	-	-	-	-	5	(0.16)	-	-
Eulimnadia										
Trichoptera	63	(1.13)	5	(0.35)	-	-	-	-	-	-
<i>Grensia praeterita</i>										
Diptera	1536	(27.46)	393	(27.16)	68	(16.75)	1620	(52.11)	494	(20.08)
<i>Polypedilum</i> sp.	-	-	-	-	-	-	5	-	19	-
<i>Protanypus</i> sp.	-	-	184	-	-	-	73	-	-	-
<i>Microtendipes</i> sp.	-	-	116	-	-	-	-	-	-	-
<i>Microsectra</i> sp.	-	-	19	-	-	-	-	-	-	-
<i>Procladius</i> sp.	58	-	5	-	24	-	995	-	271	-
<i>Cryptochironomus</i> sp. A	-	-	5	-	-	-	58	-	-	-

(Continued)

Table 29. Continued.

Taxon	A	(%)	B	(%)	C	(%)	D	(%)	E	(%)
<i>Cryptochironomus (viridulus</i> form)	-	-	-	-	-	-	10	-	-	-
<i>Chironomus</i> sp.	1463	-	15	-	-	-	353	-	130	-
<i>Trichocladius</i> sp.	-	-	-	-	-	-	-	-	5	-
<i>Monodiamesa</i> sp.	-	-	10	-	-	-	-	-	19	-
<i>Zalutschia lingulata</i>	-	-	5	-	44	-	-	-	-	-
<i>Stictochironomus</i> cf. <i>rosenschoeldi</i>	-	-	5	-	-	-	-	-	-	-
<i>Cladotanytarsus</i> sp.	-	-	-	-	-	-	126	-	-	-
<i>Conchopelopia</i> sp.	15	-	-	-	-	-	-	-	-	-
<i>Phaenopsectra</i> sp.	-	-	-	-	-	-	-	-	24	-
<i>Cryptocladopelma</i> sp.	-	-	29	-	-	-	-	-	26	-
Mollusca	1314	(23.49)	638	(44.09)	-	-	1217	(39.14)	1362	(55.37)
<i>Pisidium</i> spp.	1077	-	565	-	-	-	990	-	1183	-
<i>P. ventricosum</i> (<i>rotundatum</i> form)	-	-	-	-	-	-	101	-	150	-
<i>Sphaerium nitidum</i>	15	-	-	-	5	(1.23)	126	-	29	-
<i>Valvata lewisi</i>	-	68	-	-	-	-	-	-	-	-
<i>Valvata</i> sp.	-	5	-	-	-	-	-	-	-	-
<i>Physa</i> sp.	222	-	-	-	-	-	-	-	-	-
Total No. of Taxa	11	-	18	-	6	-	16	-	14	-
Total No. of Organisms/m ²	5593	-	1447	-	406	-	3109	-	2460	-
Species Diversity (d)	2.04	-	2.81	-	1.73	-	2.69	-	2.44	-
Equitability (e)	0.45	-	0.56	-	0.67	-	0.56	-	0.50	-

Table 30. Coefficient of community for the zoobenthos of Ya-Ya Lake Region III (all samples combined) and that of five survey lakes (A,B,C,D,E), summer, 1977.

Lake	Subsurface Total Suspended Solids (mg/L)	Coefficient of Community
A	0.3	25.0
B	1.1	34.3
C	3.4	20.7
D	3.2	28.6
E	1.7	22.9
Means	1.9	26.3

The results indicate that despite their close proximity and similarity in water clarity, the percentage of species common to the survey lakes and the Ya-Ya Lake Region III was relatively low, ranging from 20.7 to 34.3%. In the clearest survey lake (Lake A), standing crop was high (5,593 organisms/m²) and the Amphipoda:Diptera ratio was low (0.09), whereas in the most turbid survey lake (Lake C), standing crop was low (406 organisms/m²) and the Amphipoda:Diptera ratio high (3.2). Lake C also had the lowest taxonomic diversity (6) and species diversity (1.73).

Zoobenthos and Suspended Sediment Standards

A "Macroinvertebrate Standard" has been proposed to provide an assessment of the biological effects of sedimentation during pipeline construction in the North (Berger, 1977). The presumption is that the condition of the resident zoobenthic community reflects conditions in the recent past and therefore serves as a continuous, cumulative monitor. The proposed standard would be based on the Shannon Diversity Index, and a value of more than 25% (±) from the baseline value would be presumed to be indicative of ecological damage (or change) arising from the addition of finely-divided solids. In lakes or ponds, it was recommended that the direction of sampling sites from the source of siltation should be that of maximum effect, depending upon currents and wind. Berger suggests that a control or "natural" sample should be taken in a very similar nearby waterbody, or in an unaffected part of the same one.

The applicability of this method can be assessed in a preliminary way by using data generated during this study. There are significant differences in Shannon-Weaver Species Diversity* ($\bar{d}$) Indices between Regions I and II, the more turbid areas of the lake, and Region III, the clearer area, which are probably related, in large part, to the effects of sedimentation. Flow from the Mackenzie River, which carries turbid water into Ya-Ya Lake can be considered comparable to a point source of turbid water such as drainage down a pipeline or road right-of-way.

If Region III is considered to be the control or natural area and Regions I and II are considered to be the affected areas, does the difference between them, in fact, exceed 25% of the $\bar{d}$ value for the control area? The answer depends on the kinds of comparisons being made. In the simplest situation, the comparisons would be made between two sampling stations, one in the affected and one in the control area. If in 1977, the sampling location in the affected area in Regions I and II had happened to coincide with Station I where the lowest $\bar{d}$ value (1.78) was recorded, a percentage difference greater than 25% would have been demonstrable for any station in Region III except Station 10 (i.e., 4 of 5 possible control stations). If, on the other hand, the station in the affected area had coincided with Station 2 where the

*The Shannon Diversity Index which Berger recommends is virtually identical to the Shannon-Weaver Diversity Index used here. The latter is preferred by the Environmental Protection Agency (EPA) in the United States.

highest $\bar{d}$ value (2.41) was recorded, none of the possible control stations would have indicated percentage differences greater than 25%. The 1978 data are similar. While the low value for the affected area (0.61 at Station 2) differed by at least 25% from all 5 of the possible controls, the high value (2.34 at Station 1) differed from only (Station 9) by more than 25%. Thus, comparisons based on $\bar{d}$ values for single sampling stations in each of the affected and control areas might indicate that there has been no adverse impact on the zoobenthos community even though it is known from other more extensive data (Table 28), that there are significant differences. At the very least, sampling stations within both affected and control areas should be replicated. This is most important within the affected area where variability between stations would presumably be greatest. In 1978, there was a 283% difference between the lowest (0.61 at Station 2) and highest (2.34 at Station 1) $\bar{d}$ values for stations within the affected area.

With regard to the use of nearby similar lakes as controls, as indicated in Table 31, none of the 5 survey lakes had a zoobenthic community which was even 35% similar to that of stations in Region III of Ya-Ya Lake. In addition, two of the survey lakes (A and C) had $\bar{d}$ values (Table 29) which were, respectively, 27% and 38% lower than the average $\bar{d}$ value (2.81) for Region III of Ya-Ya Lake. Because these values are already low, it would be more difficult to demonstrate a 25% decline in the $\bar{d}$ values for affected areas. There are, therefore, obvious difficulties in

Table 31. Shannon Weaver diversity indices ($\bar{d}$), by stations and regions for zoobenthos in Ya-Ya Lake
N. W. T., 1977 and 1978.

Region Station	Region I			Mean Region II Regions I&II					Mean Region III				Mean Region III	
	2		3	4		5	6		7	8		9		10
	1													
$\bar{d}$ 1977	1.78	2.41	1.98	2.01	1.80	2.00	3.04	2.91	3.16	3.16	2.08	2.87		
% difference from lowest $\bar{d}$ value for Regions I & II							41	39	44	44	14	38		
% difference from highest $\bar{d}$ value for Regions I & II							21	17	24	24	-16	16		
$\bar{d}$ 1978	2.34	0.61	1.23	1.31	1.65	1.43	2.57	2.58	2.71	3.31	2.55	2.74		
% difference from lowest $\bar{d}$ values for Regions I & II							76	68	66	85	76	78		
% difference from highest $\bar{d}$ values for Regions I & II							9	9	14	29	8	15		
Means	2.06	1.51	1.66	1.66	1.73	1.72	2.81	2.75	2.94	3.24	2.32	2.81		

applying data for other control lakes in attempting to assess the status of zoobenthic populations. It would appear that the best control areas are within the same body of water as the affected area and probably in areas of similar habitat, particularly substrate type.

Conclusions

Silt carried into the southern end of the Ya-Ya Lake system had a discernible effect on the species composition and relative abundance of the zoobenthos. Among the dominant groups, Amphipoda appeared to be more abundant in the silty area whereas Diptera was more abundant in the clear area. Studies on the community response to siltation indicate that parameters such as species diversity, equitability, and taxonomic diversity all appeared to be negatively correlated with siltation. Standing crop, although seemed to be higher in the clear area, did not differ significantly between silty and clear areas. The applicability of the "Macro-invertebrate Standard" proposed to provide an assessment of the biological effects of sedimentation (Berger, 1977) was assessed in a preliminary way using data obtained from this study. The results indicate that high replication of sampling effort would be required before the differences in community diversity of the silted and clear area became obvious.

FISH

By

P.J. McCart, Ph.D.

FISH

Introduction

Fish are the aquatic organisms which, in northern lakes, are directly utilized by man in sport, commercial, and domestic fisheries. Fish obtained in domestic fisheries are used as food for both humans and dogs. Many species of fish, adapted to clear waters and clean substrates, can be adversely affected by sedimentation in lakes, others, in contrast, are favoured by heavy sediment loads.

The purposes of the fish studies reported here were to examine the distribution and life histories of various species in Ya-Ya Lake, in relation to sediment loads, to determine whether first, there were any readily discernible effects of sedimentation and second, whether there might be species indicative of sediment conditions within the lake.

Methods

Fish were sampled at three stations (1, 2, and 3) in Region I and four stations (6, 8, 9, and 10) in Region III (Figure 1). There was no sampling in Region II.

Methods of Capture

Fish were captured with gillnets, and by angling. Each gillnet set was of approximately 24 h duration and the gillnets used were multiple mesh research gangs. Each gang measured 46 m in length by 2.4 m deep. Each gang consisted of six panels of different mesh sizes arranged in the following order: 2.5, 5.1, 11.4, 6.4, 3.8, and 8.9 cm stretched mesh.

During the first sampling period (summer 1977) two gillnet panels were set in the vicinity of each fish sampling station. One panel was set perpendicular to shore at the surface in shallow water. The second panel was set offshore on the bottom in deeper water. The depths of the latter sets ranged from 2 m (South Basin) to over 40 m (North Basin), depending on location. Because these offshore sets caught almost no fish, they were discontinued during the spring 1978 sampling period. During this sampling period, a single panel was set perpendicular to shore in shallow water.

A 6 m marquisette beach seine was used to sample typical shoreline habitat in the vicinity of each fish sampling site. Two hauls, each measuring 50 m in length, were taken at each station.

Angling consisted of trolling or casting from shore with lures. Only the clear north basin was angled.

Life History Analysis

Specimens of each major fish species were retained for life history analysis. An attempt was made to collect specimens from the entire size range of each species and excess numbers within any size range were released alive. Retained specimens were dissected in the field laboratory.

In the field laboratory, each fish was measured to the nearest mm and weighed to the nearest 0.1 g. Gonads were removed and weighed to the nearest 0.1 g. Egg diameters were determined to the nearest 0.1 mm by calculating the mean diameter of 10 fresh eggs of the largest size class lined up in a row. The eggs were not water hardened.

Fish were classified in three broad reproductive categories based upon examination of the gonads. Fish were classified either as "immature" (negligible gonadal development), "mature" (sufficient gonadal development to indicate that the fish would spawn during the year of capture), or "non-spawner" (some gonadal development but would not spawn in the year of capture).

Mature fish were further classified as either "green" (body cavity filled with developing sex products but no sex products could be expressed from the vent by gentle pressure on the abdomen), "ripe" (body cavity filled with sex products which could be easily expressed by gentle pressure), or "spawned out" (body cavity empty

or mostly empty of sex products with evidence of recent spawning).

Otoliths were removed, stored in glycerin, and used for aging all fish except pike. Scales were removed from pike, placed between glass microscope slides, and used for age determination.

The stomach contents of all fish dissected were examined and identified, when possible, to major taxa. The results are expressed as per cent occurrence of food items in the stomachs examined.

Results

Distribution and Relative Abundance of Species

A total of 16 species was taken during the study period (Table 32). There was a general decline in the number of species taken from Station 1 through Station 10. Within Region I (Stations 1, 2, and 3), the number of species taken at individual stations ranged from 10 to 12 with an average of 11. Within Region III, the number of species ranged from 5 to 9 with an average of 6.7. The smallest numbers of species were taken at Stations 9 and 10, the two farthest from the influence of the Mackenzie River water.

More fish were captured at stations in Region I (107 to 190 fish with a mean of 147.0) than at stations in Region III (40 to 81 fish with a mean of 61.0) though the effort at each station was approximately equal. While this may be, in large part, the

Table 32. Total numbers of fish, by species taken at sample stations in Ya-Ya Lake, 1977 and 1978. Catches by all gear combined.

Common Name	Scientific Name	Mean Catch/Station Region		
		N	I	III
Inconnu	<i>Stenodus leucichthys nelma</i> (Pallas)	10	1.3	1.2
Humpback whitefish	<i>Coregonus clupeaformis</i> (Mitchill)	61	8.3	9.0
Broad whitefish	<i>Coregonus nasus</i> (Pallas)	61	8.0	9.2
Least cisco	<i>Coregonus sardinella</i> Valenciennes	34	4.7	5.0
Arctic cisco	<i>Coregonus autumnalis</i> (Pallas)	22	2.3	3.7
Juvenile whitefish	<i>Coregonus</i> spp.	85	20.3	6.0
Lake trout	<i>Salvelinus namaycush</i> (Walbaum)	29	0.3	7.0
Boreal smelt	<i>Osmerus eperlanus</i> (Linnaeus)	3	1.0	0.0
Pond smelt	<i>Hypomesus olidus</i> (Pallas)	8	2.0	0.5
Northern pike	<i>Esox lucius</i> Linnaeus	54	9.3	4.0
Lake chub	<i>Couesius plumbeus</i> (Agassiz)	2	0.7	0.0
Longnose sucker	<i>Catostomus catostomus</i> (Forster)	26	7.0	1.2
Trout-perch	<i>Percopsis omiscomaycus</i> (Walbaum)	133	44.3	0.0
Burbot	<i>Lota lota</i> (Linnaeus)	6	2.0	0.0
Ninespine stickleback	<i>Pungitius pungitius</i> (Linnaeus)	2	0.0	0.5
Slimy sculpin	<i>Cottus cognatus</i> Richardson	43	0.3	10.5
Spoonhead sculpin	<i>Cottus ricei</i> (Nelson)	106	34.7	0.5
Total No. of species		16	11.0	6.7
Total Catch		685	147.0	61.0

(Continued)

Table 32. Continued.

Common Name	Station Number									
	Region I			Region III						
	1	2	3	6	8	9	10			
Inconnu	1	1	3	5	-	-	-			
Humpback whitefish	4	9	12	11	16	5	4			
Broad whitefish	5	5	14	7	3	20	7			
Least cisco	8	-	6	-	20	-	-			
Arctic cisco	1	1	5	8	7	-	-			
Juvenile whitefish	1	40	20	16	8	-	-			
Lake trout	-	-	1	-	14	8	6			
Boreal smelt	-	3	-	-	-	-	-			
Pond smelt	-	6	-	-	2	-	-			
Northern pike	10	3	15	19	4	2	1			
Lake chub	-	1	1	-	-	-	-			
Longnose sucker	6	11	4	5	-	-	-			
Trout-perch	57	34	42	-	-	-	-			
Burbot	-	6	-	-	-	-	-			
Ninespine stickleback	-	-	-	-	2	-	-			
Slimy sculpin	1	-	-	4	5	11	22			
Spoonhead sculpin	13	70	21	2	-	-	-			
Total No. of Species	10	12	11	8	9	5	5			
Total Catch	107	190	144	77	81	46	40			

result of a real difference in the abundance of fish in the two regions of the lake, it probably also reflects the fact that the methods used to take fish, gillnet and beach seine, are both more effective in turbid water because fish are less able to avoid capture.

From the data included in Table 32, fish species in Ya-Ya Lake can be classified on the basis of their distribution with respect to suspended sediment concentrations.

1. Species occurring only in Region I: boreal smelt, lake chub, trout-perch, and burbot. Of these, only the trout-perch was captured in large numbers. It was, in fact, the most abundant species in catches in Region I.
2. Species occurring only in Region III: ninespine stickleback. This was the only species which was captured only in Region III and then only in very small numbers.
3. Species occurring in approximately equal abundance in both regions: humpback whitefish, broad whitefish, inconnu, least cisco, Arctic cisco. Both the whitefish species were common in Regions I and III. The two ciscoes were moderately abundant in both regions but neither species was taken at Stations 9 and 10, the most extreme locations in Region III. The inconnu was rare but present in both Regions I and III though in the latter it was only taken at Station 6. When examined on a station by station rather than on a regional

basis, the data suggest that the ciscoes and the inconnu prefer the shallow, turbid end of the lake.

4. Species occurring in both regions but with a predominance in Region I: juvenile whitefish, northern pike, longnose sucker, spoonhead sculpin. The juvenile whitefish were young-of-the-year of humpback and broad whitefish, from 14 to 43 mm fork length, which are difficult to distinguish during the early stages of their life history. They were not found at Stations 9 and 10. The northern pike was taken at all stations but was commonest at Stations 1, 3, and 6, in the turbid end of the lake. In Region III, the longnose sucker and the spoonhead sculpin were taken at Station 6 only. The distribution of the latter species is the reverse of the related slimy sculpin. Though the two species overlap at Station 6, their distributions are otherwise disjunct.

5. Species occurring in both regions but with a predominance in Region III: lake trout, slimy sculpin. The lake trout is generally characteristic of clear lakes and, except for a single specimen taken at Station 3, all the fish captured during the study were taken well uplake, at Stations 8 through 10. The slimy sculpin was the most abundant fish in samples from Region III. As previously indicated, its distribution is the reverse of that of its close relative, the spoonhead sculpin.

In Table 33, the distribution of fish species in Ya-Ya Lake is

Table 33. Habitats in which fish species occurred during the study period.

Species	HABITAT TYPE				Ya Ya Lake			
	Channels		Lakes		Region I	Region III	Stations 9 & 10	
		clear, no clear, connection to river channels	turbid connected to river channels					
Arctic lamprey	2				-	-	-	
Inconnu	14		4	8	+	+	+	
Humpback whitefish	14		6	9	+++	+++	+++	
Broad whitefish	8	3	5	8	+++	+++	+++	
Least cisco	13	1	4	8	++	++	-	
Arctic cisco	4			2	++	++	-	
Round whitefish	4			1	-	-	-	
Lake trout			2		+++	+++	+++	
Arctic char	2				-	-	-	
Boreal smelt	1				+	+	-	
Pond smelt	13	1	3	8	+	+	+	
Northern pike	15	2	6	7	++	++	-	
Lake chub	5			1	+	-	-	
Longnose sucker	12			6	+++	+	-	
Trout-perch	13		3	10	+++	-	-	
Burbot	12		3	7	+	-	-	
Ninespine stickleback	15	4	4	8	-	+	-	
Fourhorn sculpin	1				-	-	-	
Slimy sculpin			3	8	+	+++	+++	
Spoonhead sculpin	15		3		+++	+	-	
Number of each habitat sampled	21	4	6	14	1	1	1	
Number of species collected/habitat	18	5	12	15	15	12	5	

compared with the distribution of fish species among habitat types elsewhere in the Mackenzie Delta. The data indicate that, in the number of species (15) and in the identity of individual species (12 of the 15 species are common to both), Region I of Ya-Ya Lake is similar to turbid lakes connected to river channels elsewhere in the Mackenzie Delta. Likewise, the fish fauna of Region III is similar to that of clear lakes connected to river channels (12 species each, 10 of which are common). Also in Table 33, Stations 9 and 10 have been distinguished from others as the most extreme habitats within Region III, and compared with data for various lake types. In terms of numbers of species (5), the fish fauna is depauperate and similar to that of clear lakes unconnected to river channels; however, only two species are common to both.

Most of the species taken during sampling in Ya-Ya Lake also occur in channels in the Outer Delta in the vicinity of Ya-Ya Lake (Tables 32 and 33). There are only two exceptions, the slimy sculpin and the lake trout, both of which were taken almost exclusively in Region III. Both species appear to have a strong preference for clear waters and neither has been taken in turbid lakes in the Outer Delta (Table 33). The lake trout, as its name suggests, is primarily a lacustrine species, rarely entering or spawning in rivers. The slimy sculpin is found in both lakes and streams. In the latter it is frequently a codominant with the Arctic grayling (*Thymallus arcticus*) in small, clear tributaries of the Mackenzie River.

Life Histories of Major Species

The following are brief life histories of those species from Ya-Ya Lake for which samples are of sufficient size to permit comparisons either between species or between areas.

Humpback Whitefish

Lindsey et al. (1970) consider *Coregonus clupeaformis* a "species complex". The species complex includes all the deep-bodied North American forms commonly referred to as "humpback whitefish" or "lake whitefish" (including *clupeaformis*, *nelsonii*, and *pidschian*). A form with intermediate modal gillraker counts (24-25) which occurs in the Mackenzie River Delta (McPhail and Lindsey, 1970; Percy, 1975) is, for purposes of discussion, simply referred to as the humpback whitefish.

Humpback whitefish typically occur in lakes, but are also taken in larger rivers and brackish water. The species comprises a large portion of domestic fishery catches of the Mackenzie Valley (Hatfield et al., 1972). Reviews of the general biology and life history of humpback whitefish in the Mackenzie River drainage (McPhail and Lindsey, 1970; Hatfield et al., 1972; Stein et al., 1973; Jessop et al., 1973, 1974; Slaney, 1974; Jessop and Lilley, 1975; Percy, 1975; de Graaf and Machniak, 1977) and along the Beaufort Sea coast (Kendel et al., 1974; Slaney, 1975) have been recently published.

The aged sample of humpback whitefish includes a full range of sizes from 48 to 558 mm fork length and several identifiable young-of-the-year (Table 34). It is likely that many of the unidentifiable young-of-the-year (*Coregonus* sp.), which ranged in length from 14 to 43 mm, are also humpback whitefish.

Data relating length to age are presented in Table 34 and Figure 23. The oldest and longest fish taken was age 17 and 558 mm in length. There is no apparent difference between the length/age relationships of humpback whitefish taken in Region I and those taken in Region III. The species is highly mobile in the Mackenzie Delta (de Graaf and Machniak, 1977) and it is likely that fish at either end of the lake constitute a single population. A comparison of length data for Ya-Ya Lake with those for humpback whitefish from other waterbodies in the vicinity (Figure 23) suggests that the growth rates are very similar and unlikely to be significant within any individual age class.

Humpback whitefish ate a variety of foods (Table 35). The most frequently occurring identifiable items among samples taken in Region I were gastropods and pelecypods (12% occurrence for both groups); however, a large percentage (36%) of the stomachs taken in this area were empty, compared with only 27% for fish taken in Region III. In the latter region, the most frequently occurring items were also gastropods (44%) and pelecypods (48% occurrence), followed by isopods (37%) and amphipods (23%). Overall, the

Table 34. Age and length of major fish from Ya-Ya Lake, 1977 and 1978. Total lengths for sculpins, otherwise fork length.

Age	Humpback Whitefish			Broad Whitefish			Lake Trout		
	N	X	Range	N	X	Range	N	X	Range
0	2	48	-	12	54	46- 64			
1	1	77	-	2	61	57- 65			
2	5	116	102-150						
3	5	163	155-171						
4	3	187	179-199						
5	4	230	202-290						
6	2	243	222-265	5	392	361-419			
7	1	200	-	2	454	443-465			
8				11	435	360-480			
9	6	347	302-383	5	447	393-479	4	405	361-458
10	8	410	389-459	4	473	446-520	1	400	
11	8	390	335-431	4	483	435-515	2	393	339-448
12	4	460	428-461	2	531	-			
13	11	426	372-476	3	463	454-475	1	392	-
14	5	447	428-461				2	444	424-465
15	3	449	446-453				2	557	434-681
16	1	428	-						
17	1	558	-				3	480	439-520
18							3	509	481-527
19							1	648	-
20							5	564	485-685
21									
22									
23							1	567	
24									
25									
26									
27							1	680	
31							1	606	
32							1	835	

(Continued)

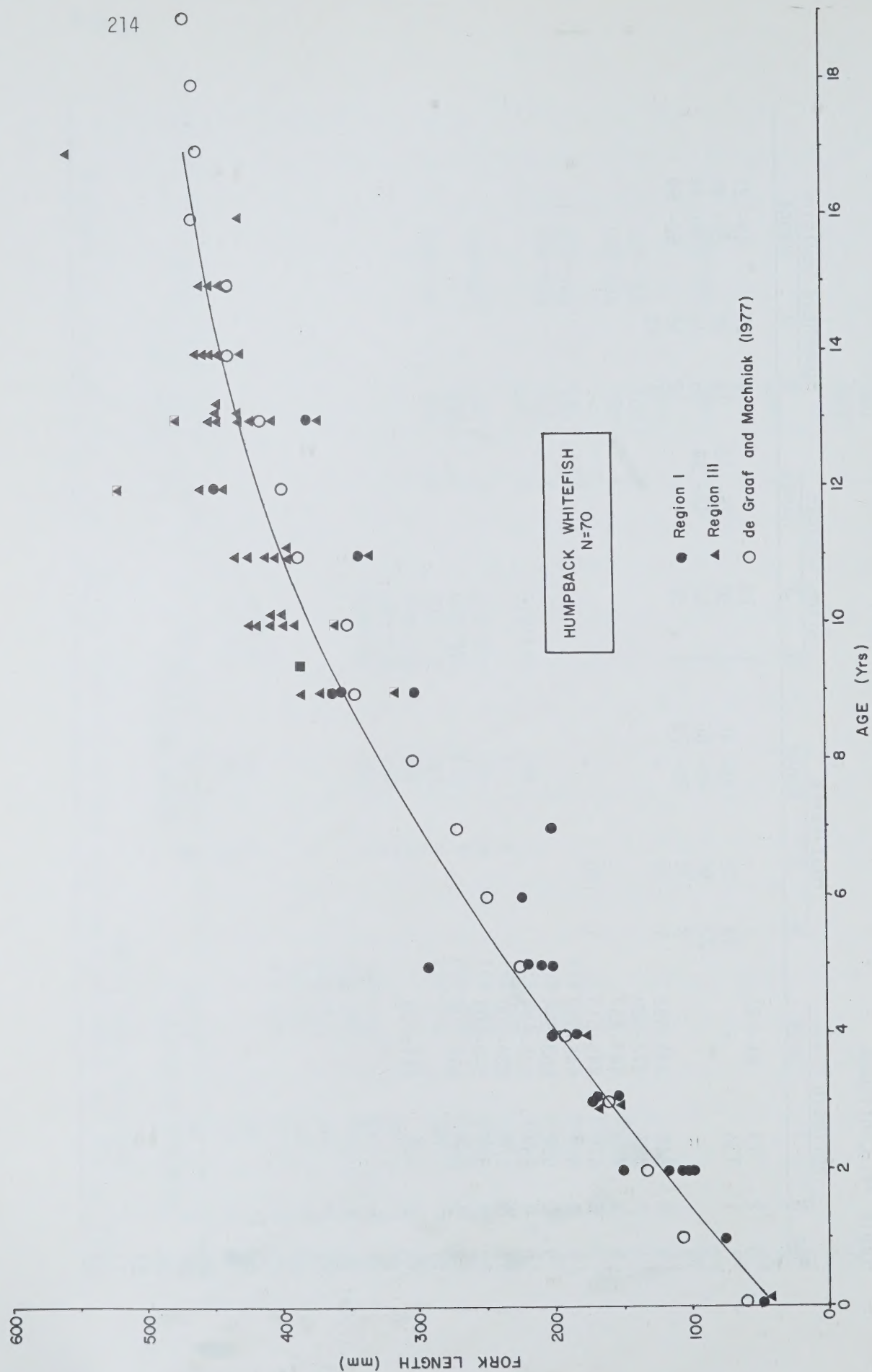


Figure 23. Age-length relationship for humpback whitefish from Ya-Ya Lake, N.W.T. Open circles indicate means for age groups from de Graaf and Machniak (1977).

Table 35. Per cent occurrence of food items in stomachs of major species of fish taken from Ya-Ya Lake, 1977 and 1978.

Species Region	a _{HPWF}		b _{BRWF}		c _{LKTR}		d _{PIKE}		e _{TRPH}		f _{SLSC}		g _{SPSC}	
	I	III	I	III	III	I	I	III	I	III	I	III	I	III
Number sampled	25	43	12	35	28	24	27	64	1	11	86			
% empty	36	16	41	8	17	80	51	9	100	9	11			
Crustacea														
Conchostraca		6		11	3								1	
Ostracoda	4												6	
Copepoda	4							17			27		1	
Mysidacea	4				3			6			54		43	
Isopoda		37		2	7		14						2	
Amphipoda	4	23	33	14	60		22	34			9		15	
Insecta														
Plecoptera				2									10	
Odonata					3		3							
Hemiptera													1	
Trichoptera				5							9		5	
Diptera														
Chironomid larvae	8	6	8	5	3			70			73		29	
Unidentified larvae	4	4		8				18					2	
Unidentified adults		2		11	7			1			9		4	
Mollusca														
Gastropoda	12	44		60										
Pelecypoda	12	48		28				7			9			
Fish														
<i>Coregonus</i> sp.					7	16	11							
<i>Cottus</i> sp.					3	4								
Unidentified sp.	4				7	4								

(Continued)

Table 35. Continued.

Species Region	HPWF		BRWF		LKTR		PIKE		TRPH		SLSC		SPSC	
	I	III	I	III	I	III	I	III	I	III	I	III	I	III
Miscellaneous														
Sand	4	16		20	14		3						1	
Vegetative Matter	4	6	16	5	10		7						2	
Digested Matter	16		8		3		4		14		18		27	

- a Humpback whitefish
 b Broad whitefish
 c Lake trout
 d Northern pike
 e Trout-perch
 f Slimy sculpin
 g Spoonhead sculpin

frequencies of occurrence are much higher than those for Region I. In addition, the proportion of empty stomachs (16%) was less than half that in Region I. It would appear that feeding conditions for humpback whitefish are better in Region III than in Region I.

It is not known if humpback whitefish spawn in Ya-Ya Lake. The known spawning grounds of the species in the vicinity of the Mackenzie Delta include back eddies of the Mackenzie River near Arctic Red River (Stein et al., 1973) and at Horseshoe Bend on the mainstem of the Mackenzie within the Delta (Jessop et al., 1974). Most of the young-of-the-year *Coregonus* sp., which probably included humpback whitefish, were found in Region I and the more southerly portions of Region III suggesting either that these fish enter the lake from the Mackenzie River during the spring flood or that, if spawning does take place in the lake, it is concentrated near the outlet end.

Broad Whitefish

The biology of broad whitefish is not well known (Scott and Crossman, 1973). The species inhabits both lakes and rivers, and in some areas is anadromous. It is an important species in the domestic fishery of the Outer Delta. The available information on the life history of broad whitefish in the region has been reviewed by Wynne-Edwards (1952), Muth (1969), McPhail and Lindsey (1970), Hatfield et al. (1972), Stein et al. (1973), Kendel et al. (1974), Percy (1975), and de Graaf and Machniak (1977).

The aged sample of broad whitefish includes young-of-the-year and a few age 1 fish in the 46 to 65 mm length range as well as larger fish ranging from 360 to 520 mm fork length (Table 34). Fish of intermediate size are missing. The fact that humpback whitefish in the intermediate size range were captured suggests that this size range was indeed missing among broad whitefish and would have been captured had it been present.

Data relating length to age are presented in Table 34 and Figure 24. The oldest and longest fish taken were, respectively, a 13 year old male 475 mm in length and a 10 year old female 520 mm fork length. Most of the aged sample was taken in Region III. There was no apparent difference in length-age relationship between these and the small number of fish taken in Region I (Figure 24). Like the humpback whitefish, this species is highly mobile in the Mackenzie Delta (de Graaf and Machniak, 1977) and it is likely that the fish taken in the two regions constitute a single population, possibly continuous with that that occupies adjacent waterbodies within the Delta. There is a suggestion that the growth of fish in Ya-Ya Lake may be slightly better than that of fish in adjacent areas of the Mackenzie Delta (Figure 24), but the mean lengths of the latter lie within the range for Ya-Ya Lake broad whitefish and are unlikely to differ significantly.

As mature fish, broad whitefish in Ya-Ya Lake are generally longer than same-age humpback whitefish (Figures 23 and 24).

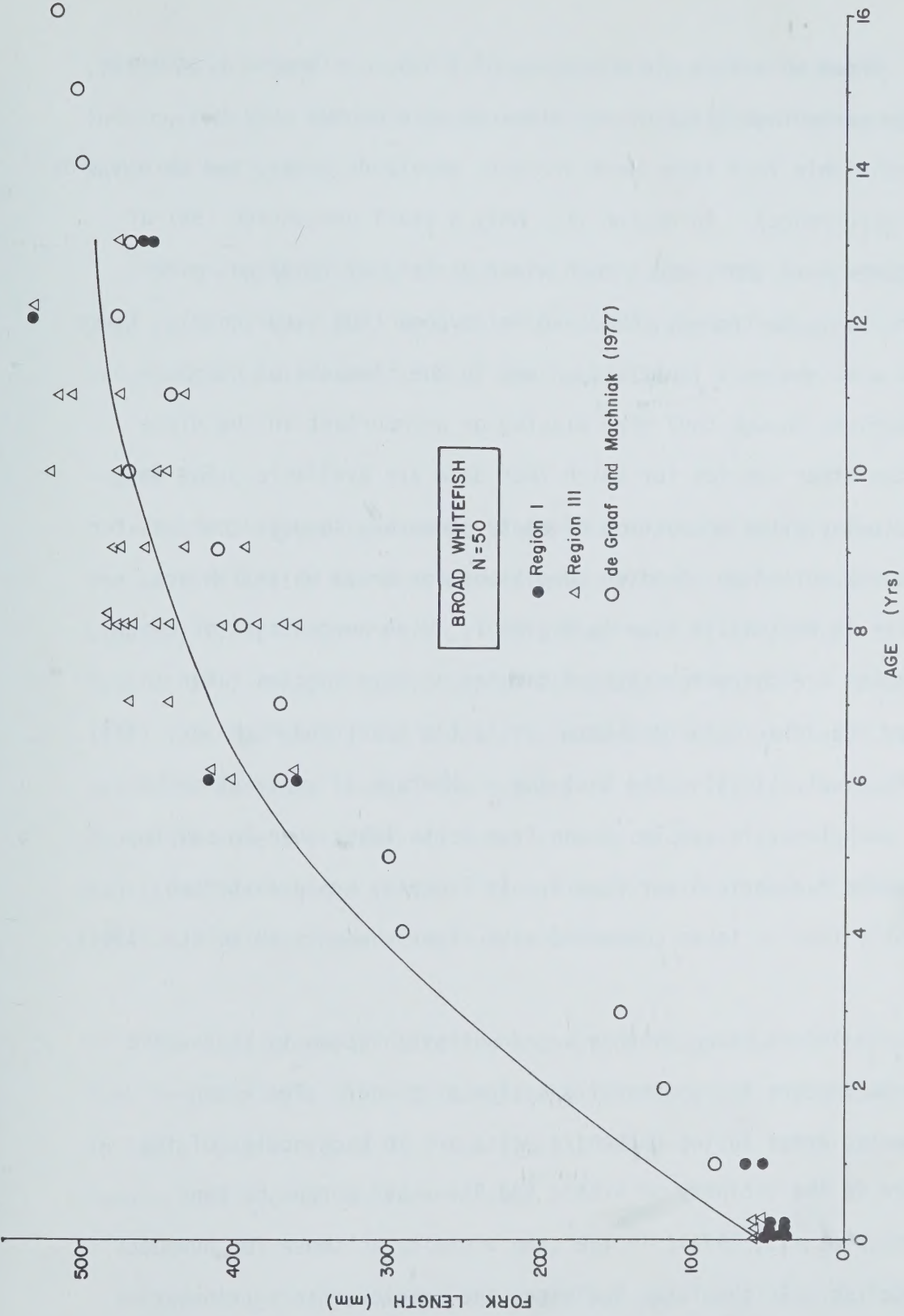


Figure 24. Age-length relationship for broad whitefish from Ya-Ya Lake, N.W.T. Open circles indicate means for age groups from de Graaf and Machniak (1977).

Broad whitefish ate a variety of foods. In Region I, where a large percentage (41%) of the stomachs were empty, only two identifiable food items were present, amphipods (33%), and chironomids (8% occurrence). In Region III, only a small percentage (8%) of stomachs were empty and a much wider variety of foods was eaten, principally gastropods (60%) and pelecypods (28% occurrence). These were also the most important groups in the stomachs of humpback whitefish, though they were missing or unimportant in the diets of the other species for which food data are available. The data, particularly the proportion of empty stomachs, suggest that, as for humpback whitefish, feeding conditions for broad whitefish are better in Region III than in Region I. High percentages of empty stomachs are characteristic of samples of this species taken in river channels in the Mackenzie Delta (de Graaf and Machniak, 1977). Stein et al. (1973) noted that the percentage of empty stomachs was much lower in samples taken from Delta lakes than in samples from the Mackenzie River itself. In Siberia, broad whitefish usually feed in lakes connected with river channels (Nikolsky, 1961).

It is not known whether broad whitefish spawn in Ya-Ya Lake but it appears to be generally a stream spawner. The known spawning areas in the Mackenzie Delta are in back eddies of the river in the vicinity of Arctic Red River and Horseshoe Bend (Jessop et al., 1974), in the same vicinity as those for humpback whitefish. In the Yukon Drainage, the species enters tributaries to spawn (McPhail and Lindsey, 1970). Nikolski and Reshetnikov

(1970) report that current is a prerequisite for gonad ripening in this species and that the gonads of fish without access to running water do not mature.

If the species does not spawn in Ya-Ya Lake, the young-of-the-year taken in the lake, most of which were captured in Region I, originate elsewhere and utilize the lake only as a nursery area.

Lake Trout

The biology of lake trout in the Mackenzie Delta area and in the western Arctic has been extensively reviewed (McPhail and Lindsey, 1970; McCart et al., 1972; Hatfield et al., 1972; Falk et al., 1973; Slaney, 1974; Craig and Wells, 1975; Percy, 1975). In the north, the species is generally slow growing, late maturing, and long lived. The species is primarily lacustrine though in some areas they do enter streams on short feeding migrations during the summer. Stream spawning can occur (Loftus, 1958) but is not known in the western Arctic.

The aged sample of lake trout covers a range from 339 to 835 mm fork length (Table 34). Data relating length to age are presented in Table 34 and Figure 25. The oldest, longest fish taken was a female, age 32, 835 mm fork length.

Lake trout ate a variety of foods but amphipods were the most frequently occurring item (60% of stomachs). The species is

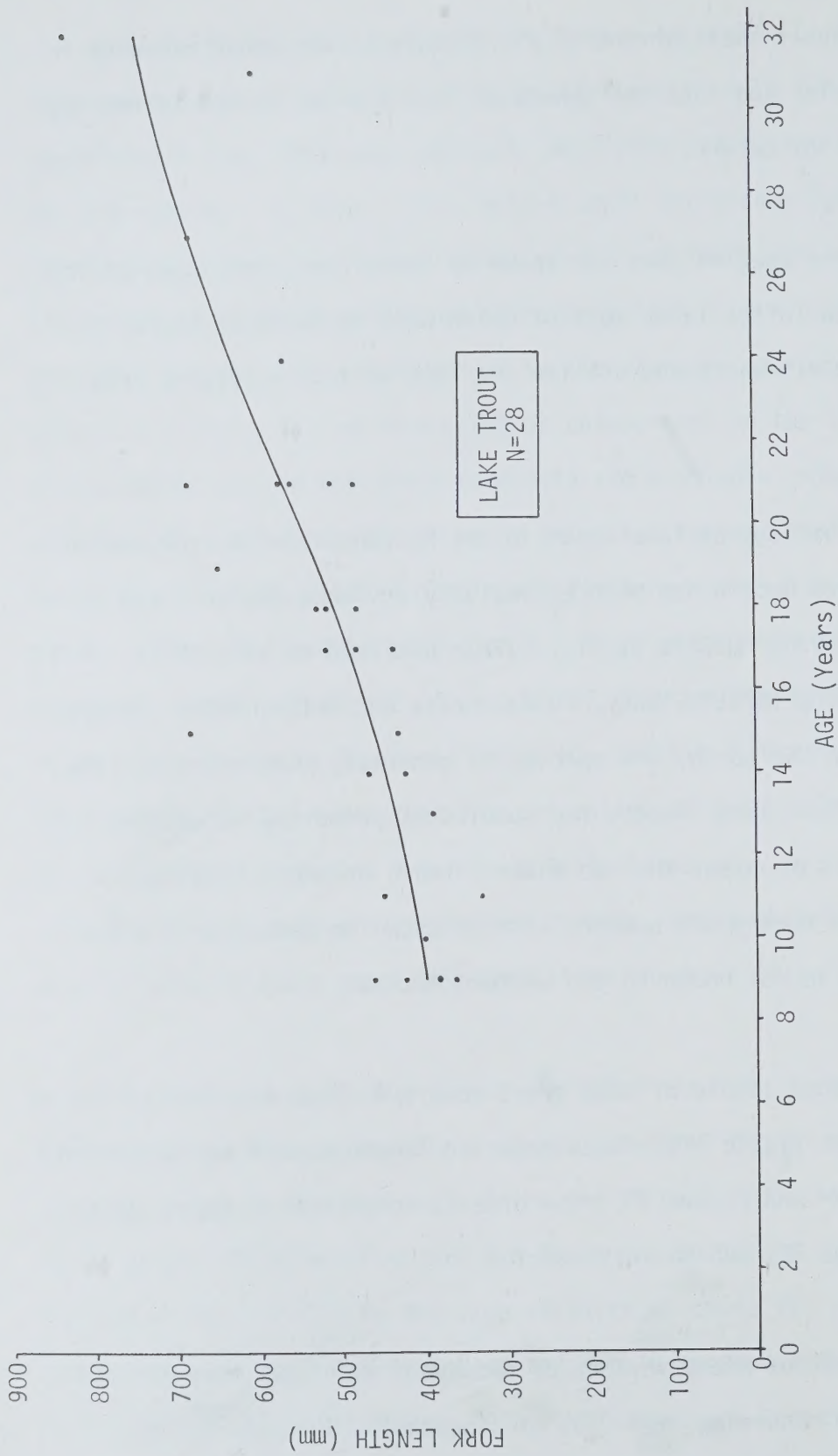


Figure 25. Age-length relationship for lake trout from Ya-Ya Lake, N.W.T.

considered to be highly piscivorous and fish, as a group, were the second most frequent food item, though far less common than amphipods.

No young-of-the-year or juvenile lake trout were taken. These life history stages are often confined to deep water and are not susceptible to capture by methods used during this study. It is likely that the lake trout in Ya-Ya Lake are a distinct population which spawns and matures entirely within the lake.

Northern Pike

The northern pike has a circumpolar distribution and in North America ranges from Alaska to Labrador. They are a highly rated game fish and form an important source of human and dog food throughout the north.

The biology of pike in northern Canada (Miller and Kennedy, 1948; McPhail and Lindsey, 1970; Hatfield et al., 1972; Stein et al., 1973; Jessop et al., 1973, 1974; Slaney, 1974, 1975; Percy, 1975) and Alaska (Alt, 1968; Cheney, 1972; Craig and Wells, 1975) has been extensively reviewed.

The sample from Ya-Ya Lake includes two age 0 and one age 1 fish, 66 to 136 mm fork length, as well as a large group of fish, ages 4 to 15, ranging in length from 325 to 735 mm fork length (Table 34). There are no fish in 137 to 324 mm length range. Both Percy (1975)

and de Graaf and Machniak (1977) report a similar size class deficiency in their samples from the Mackenzie Delta. Apparently the distributions of juvenile and adult fish within the population are segregated. It is not known where the former reside.

Data relating length to age are presented in Table 34 and Figure 26. The oldest and longest fish taken was age 15 and 735 mm fork length. There was no apparent difference in the length-age relationships of fish taken in Regions I and III (Figure 26). The length-age relationship for the Ya-Ya Lake fish is very similar to that developed by de Graaf and Machniak (1977) for other waterbodies in the vicinity. It is likely that the northern pike in Ya-Ya Lake enter from the Mackenzie River and are part of the same population that occurs elsewhere in the eastern portion of the Mackenzie Delta.

The diet of pike was more varied in Region III than in Region I and, as with the two species of whitefish, there was a smaller proportion of empty stomachs in Region III (Table 35). In Region III, the most frequently occurring foods were, in order, amphipods, isopods, and whitefish. In Region I, only fish occurred in stomachs.

A few young-of-the-year were taken in Region I of Ya-Ya Lake suggesting that the species may spawn there.

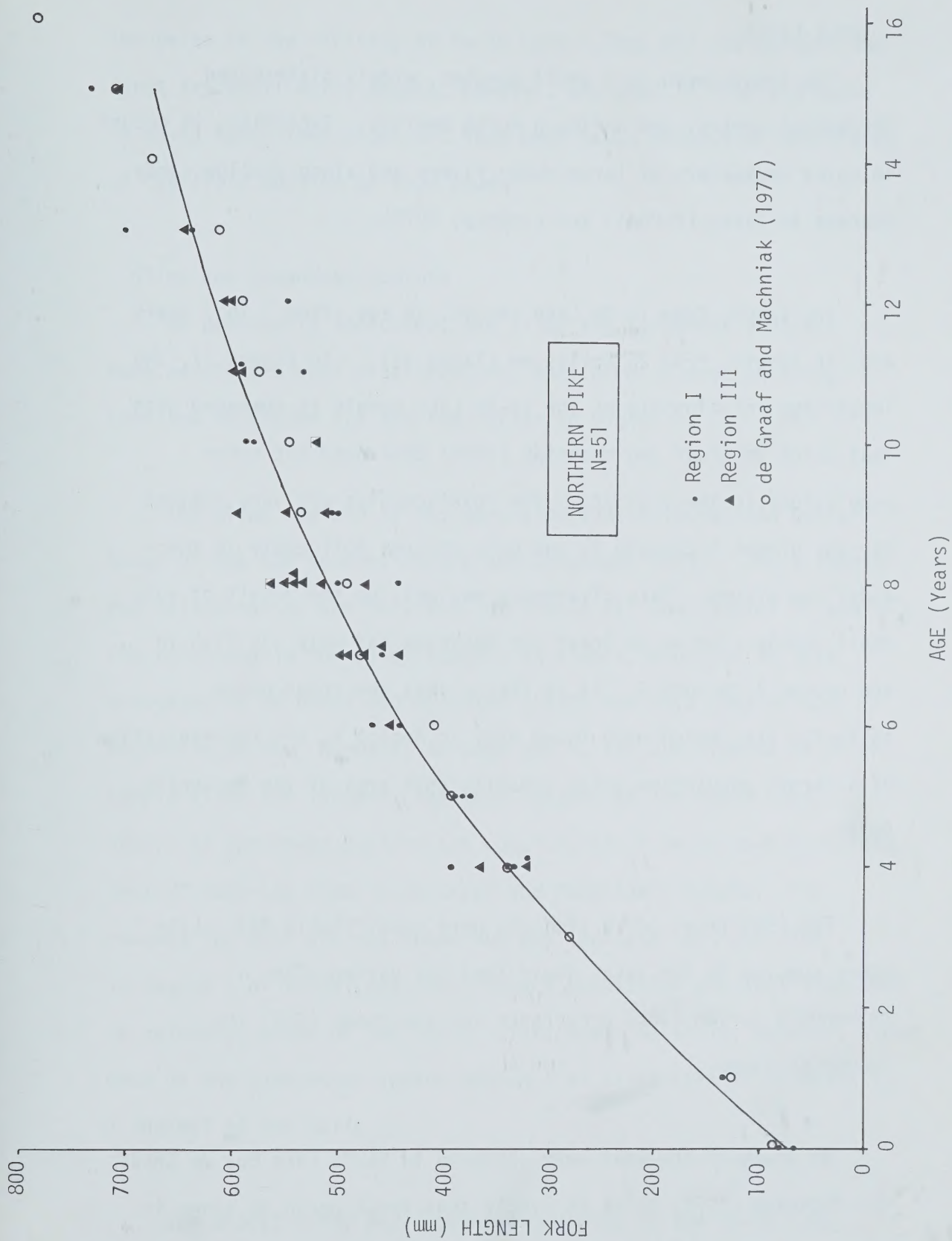


Figure 26. Age-length relationship for northern pike from Ya-Ya Lake, N.W.T. Open circles are means for age groups from de Graaf and Machniak (1977).

Trout-Perch

The trout-perch is a small species, widely distributed throughout central and northern North America. Typically, it occurs in quiet backwaters of large muddy rivers and along shallow sandy beaches in lakes (McPhail and Lindsey, 1970).

The sample from Ya-Ya Lake ranged, in age, from 1 to 7 years and, in length, from 25 to 110 mm (Table 34). In Figure 27, the length-age relationship of the Ya-Ya Lake sample is compared with that which de Graaf and Machniak (1977) developed for other populations in the vicinity. The relationships are very similar for age groups 1 through 3, and only diverge noticeably in the older age groups. This divergence may well be the result of very small sample size as de Graaf and Machniak had only six fish in age groups 4 through 6. It is likely that the trout-perch in Ya-Ya Lake, which were found only in Region I, are representative of a larger population which inhabits this area of the Mackenzie Delta.

Few (9%) trout-perch stomachs were empty (Table 35). Like other species in the lake, their food was varied with chironomid larvae (70%) occurrence and amphipods (34%) the commonest items.

No young-of-the-year were captured in Ya-Ya Lake but de Graaf and Machniak (1977) think it likely that trout-perch do spawn in

the Delta in the vicinity of Ya-Ya Lake. They did not capture the first fry until early August, however, and even if fish did spawn in Ya-Ya Lake, they might not have been taken because of the timing of the field portion of this study.

Slimy and Spoonhead Sculpin

As previously indicated, the slimy and spoonhead sculpins have nearly disjunct distributions, the former almost entirely confined to Region III and the latter to Region I.

The slimy sculpin is the more widely distributed and better known of the two species (Scott and Crossman, 1973). Their length-age relationships are very similar (Table 34, and Figures 28 and 29). The relationship for slimy sculpin is almost identical to that presented by de Graaf and Machniak (1977) for this area of the Mackenzie Delta. However, through age 3, the age classes in which sample sizes are largest, the mean lengths of the Ya-Ya Lake sample of spoonhead sculpin are consistently 5 mm or more less than that of same-age fish in de Graaf and Machniak's sample. The reasons for this are not known but may indicate that the fish in Region I of Ya-Ya Lake constitute a population distinct from that in adjoining areas of the Delta. This seems unlikely, however, since much of the open water season Region I of Ya-Ya Lake is essentially a channel of the Delta.

The oldest slimy and spoonhead sculpins in the Ya-Ya Lake

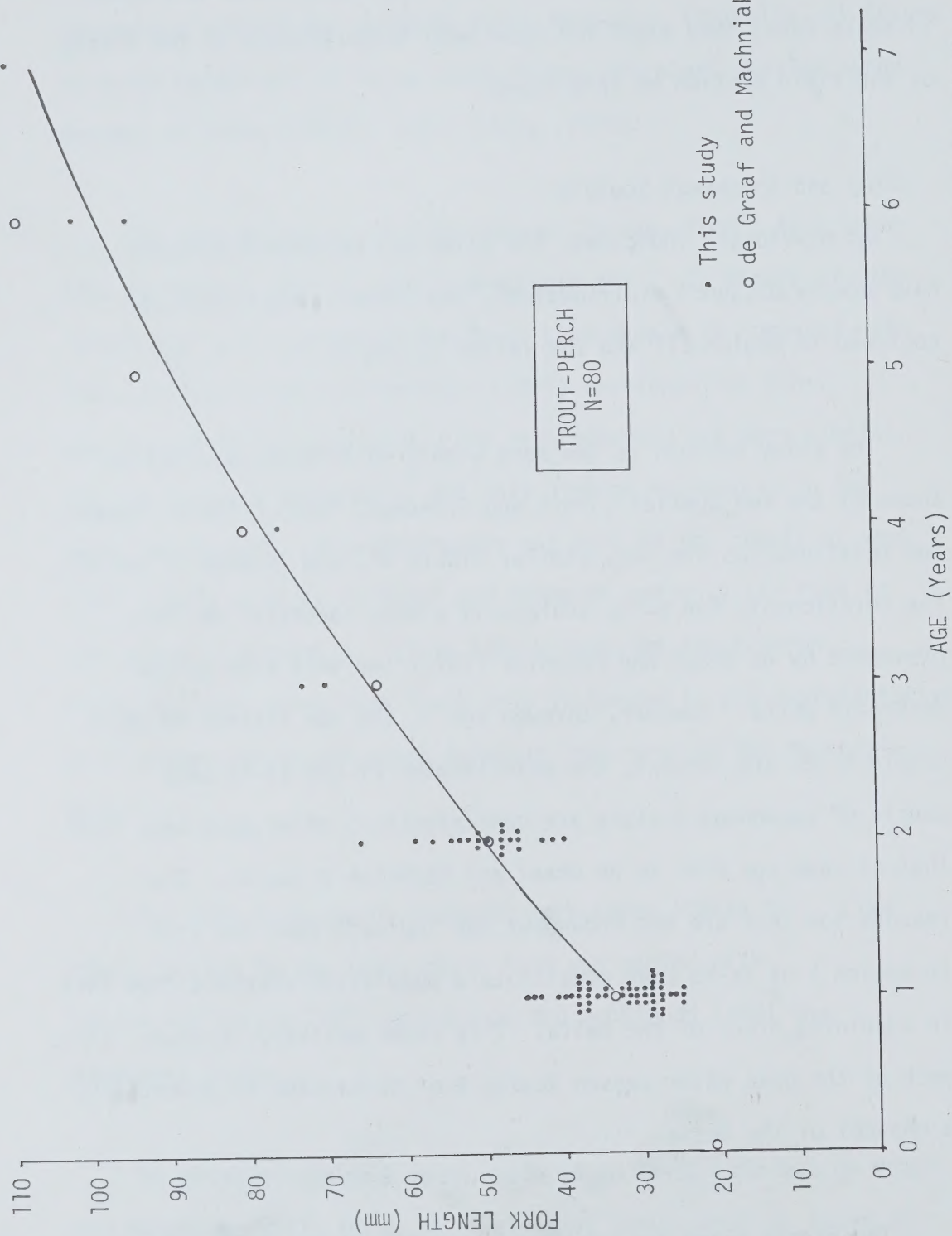


Figure 27. Age-length relationships for trout-perch from Ya-Ya Lake, N.W.T. Open circles indicate means for age groups from de Graaf and Machniak (1977).

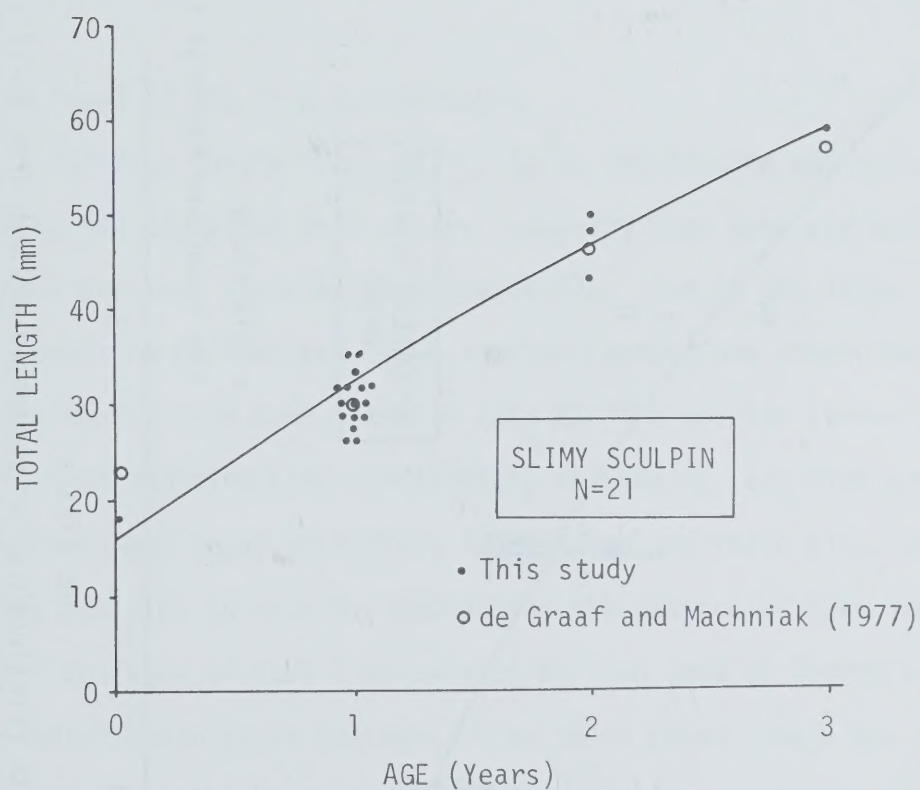


Figure 28. Age-length relationship for slimy sculpin from Ya-Ya Lake, N.W.T. Open circles indicate means for age groups from de Graaf and Machniak (1977).

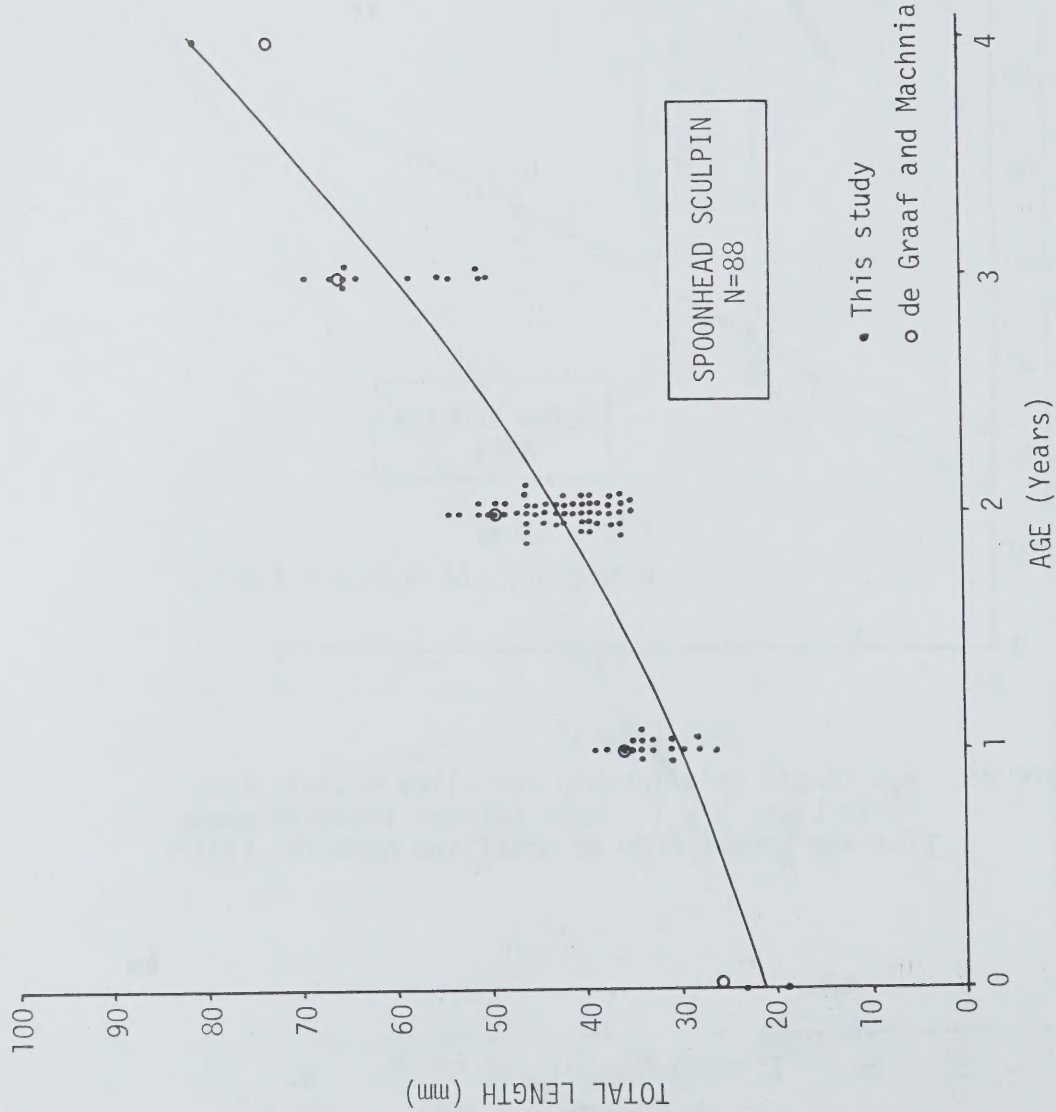


Figure 29. Age-length relationship for spoonhead sculpin from Ya-Ya Lake, N.W.T. Open circles indicate means for age groups from de Graaf and Machniak (1977).

sample were 3 and 4, respectively. de Graaf and Machniak also found a one year discrepancy in maximum ages, 4 and 5, respectively. The length-age relationships of the two species are nearly identical in the age groups in which they overlap (Table 34). The difference in the maximum lengths (59 mm for slimy and 82 mm for spoonhead) attained by the two species are probably largely due to the greater age of the spoonhead sculpin in the sample.

Fish Fauna of the Five Survey Lakes

The five survey lakes (A, B, C, D, and E) were not surveyed during the course of this study; however, some data are available from a previous study by Machniak (1977). Two of the lakes (D and E) appear to be fishless. Two species (burbot and ninespine stickleback) have been taken in Lake A; two species (broad whitefish and ninespine stickleback) in Lake B; and five species (humpback and broad whitefish, least cisco, northern pike, and slimy sculpin) in Lake C. Except for the absence of lake trout, the fish fauna of Lake C appears to be like that of Region III and the North Basin of Ya-Ya Lake. Like Ya-Ya Lake, Lake C has a direct connection to the Mackenzie Delta.

Discussion

There are several species of fish inhabiting Ya-Ya Lake which may be useful indicators of conditions with respect to suspended sediment and turbidity. Two species, the lake trout and slimy

sculpin, appear from this and other studies to be generally characteristic of clear water habitats. Two others, the trout-perch and spoonhead sculpin, appear to be largely restricted to turbid waters. Of these, the sculpin pair may prove to be most useful in monitoring habitat changes resulting from sedimentation. Where they both occur within drainage systems, intraspecific competition might be expected to reinforce the apparent difference in habitat preference.

Of the four species, the lake trout is the only one of direct economic importance. While it is taken in both domestic and commercial fisheries in the Northwest Territories, its greatest potential value is as a sports species and as an attractant to tourists. The species is very slow growing and extremely susceptible to the effects of overexploitation. Increases in suspended sediment loads in lakes, particularly in the vicinity of spawning grounds, might, together with high rates of exploitation, have long term adverse effects on populations of this species.

Also of interest is the suggestion, based largely on the proportion of empty stomachs and the variety of foods eaten, that several species, apparently tolerant of a wide range of conditions, appear to encounter better feeding conditions in the clear end of the lake. These include the humpback and broad whitefishes and the northern pike, all of them large fish, important in domestic fisheries.

Phillips (1971) summarized the literature describing the direct effects of high silt loads and sedimentation on fish production. He lists the following effects:

1) Where sediment concentrations are high and exposure is long, gill membranes may be damaged and, in severe cases, death may result.

2) Sediment can cause mortality to eggs and alevins in spawning gravels by filling in the interstices in the gravel and reducing intragravel water flow thereby reducing the supply of oxygenated water to the egg and interfering with the removal of metabolites (carbon dioxide and ammonia).

3) Sediment forms a barrier to fry emergence by blocking the spaces between stones through which fry move.

4) Survival after emergence is reduced because of a) loss of escape cover in the spaces between stones, b) reductions in the density of invertebrate food organisms.

With regard to effects on gill membranes, it is unlikely that sediment loads resulting from natural causes or from conventional developments in the north will ever reach lethal levels for a long enough period of time to cause mortality to juvenile or adult fish. Apman and Otis (1965) concluded that most fish species were

tolerant of high levels of suspended sediment and that even sensitive species were not killed until exposed to concentrations of 20,000 ppm or more for prolonged periods.

The most serious direct effects of sediment loads on fish populations are, then, those which affect the egg to fry stages in the life history. Consequently, damage is most likely to occur where there is sedimentation in the vicinity of spawning grounds or of rearing areas utilized by young-of-the-year after emergence.

Aside from early life history stages, the major effects of sedimentation on fish populations are indirect, as the result of a reduction in available food in the form of aquatic invertebrates. Studies in streams have shown that populations of salmonids were reduced in stream areas where sedimentation had reduced populations of fish-food organisms (Cordone and Pennoyer, 1960; Peters, 1962; Pautzke, 1937). Our own studies (Zoobenthos section) have demonstrated that benthic invertebrate densities are lower in the heavily sedimented than in the clearer parts of Ya-Ya Lake. There is also a suggestion that, for some species of fish, feeding conditions, especially for benthic invertebrates, are better in Region III, the clear end, than in Region I, the turbid end of the lake.

MULTIVARIATE ANALYSIS

By

R.H. Green, Ph.D.

MULTIVARIATE ANALYSIS

Introduction

Green and Vascotto (1978) have discussed the general problem of analysing the environmental factors controlling patterns of species composition in aquatic communities. They point out that:

"Ecologists often wish to determine the environmental factors which are controlling spatial distributions of the taxa present within a defined area. The field data are usually in the form of a 'samples-by-taxa' data matrix, with the samples keyed to a map of the study area. These data may be in presence-absence or in quantitative form, and should be from replicated random samples at each location so that the precision of estimates can be assessed by classical statistical methods. In association with each biological sample there are usually values determined for a number of environmental variables, chosen in the hope that they will in some sense be 'explanatory'.

"There are many approaches to the analysis of such a data matrix. We are interested in analysis which (1) efficiently reduce the species-abundance (or other taxonomic level) data to some useable form, and (2) relate these reduced biological data to the environmental data in such a way that the latter explain or predict the former."

It is possible to obtain excellent results by simply plotting distributions of taxa and environmental variables and then "looking for patterns" such has been done in the phytoplankton, zooplankton, the zoobenthos, and fish sections of this report. However, as Green and Vascotto (1978) point out, such an approach becomes inefficient with a large data matrix. The purpose of this section

of the report is to assess the suitability of using ordination and clustering techniques in analysing the Ya-Ya Lake biological data so that they can be interpreted in terms of a gradient of turbidity and/or suspended sediment concentration. Of particular interest is the possibility that this approach might be used in developing predictive models for future monitoring.

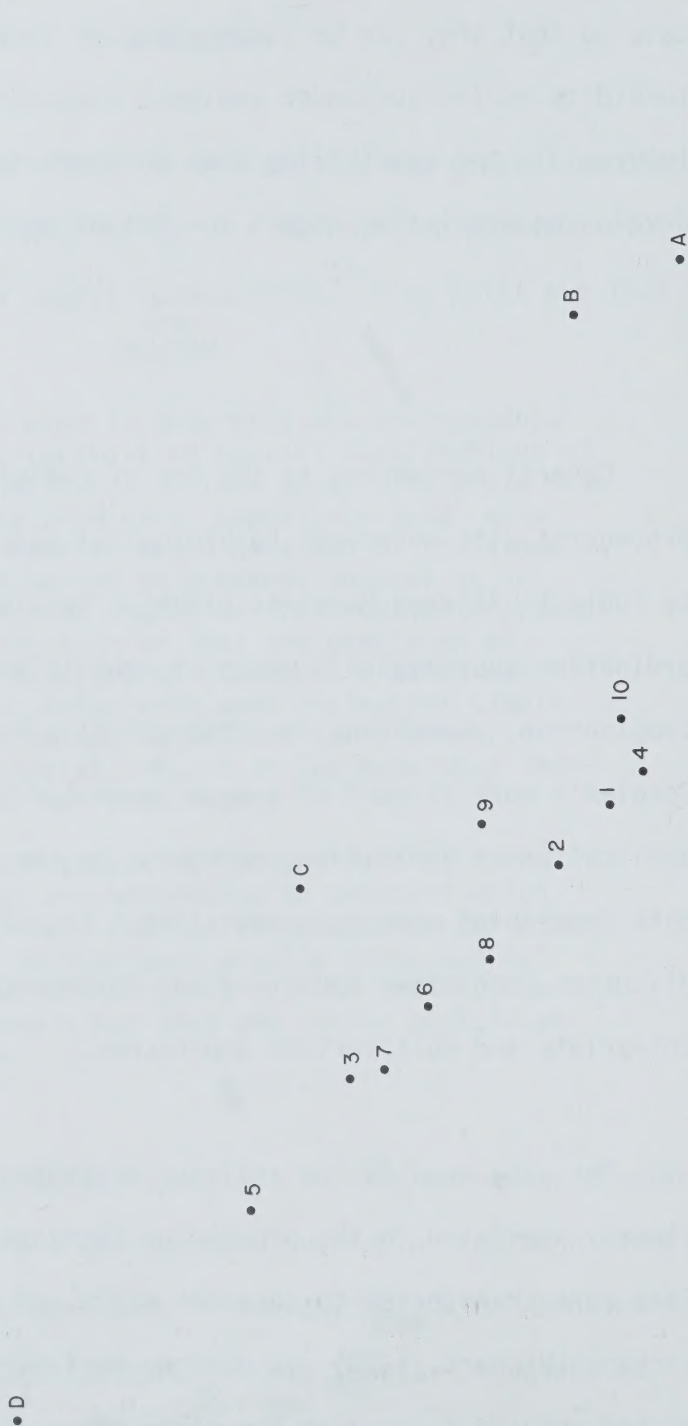
Methods

General approaches to the use of ordination and clustering procedures with reference to biological data have been outlined by Poole (1974) and Marriott (1974). Sprules (1977) applied the ordination approach to a group of aquatic organisms, the crustacean zooplankton. Green and Vascotto (1978) present a critique of Sprules's work as part of a more general discussion of the application of ordination procedures to the interpretation of data describing aquatic communities. Finally, Greene (1979) discusses predictive modelling and environmental monitoring using univariate and multivariate approaches.

The data used in the analyses described below are those already presented in the preceeding sections of this report. They were transferred to computer cards and a CLUSTAN program package (Wishart, 1975) was used to perform the ordination procedures and to produce the plots shown in Figures 30 and 31.

ZOOPLANKTON 1977

Figure 30. Principal components analysis based on the summer 1977 species abundance data for 13 species of zooplankton.



PRINCIPAL COMPONENT I

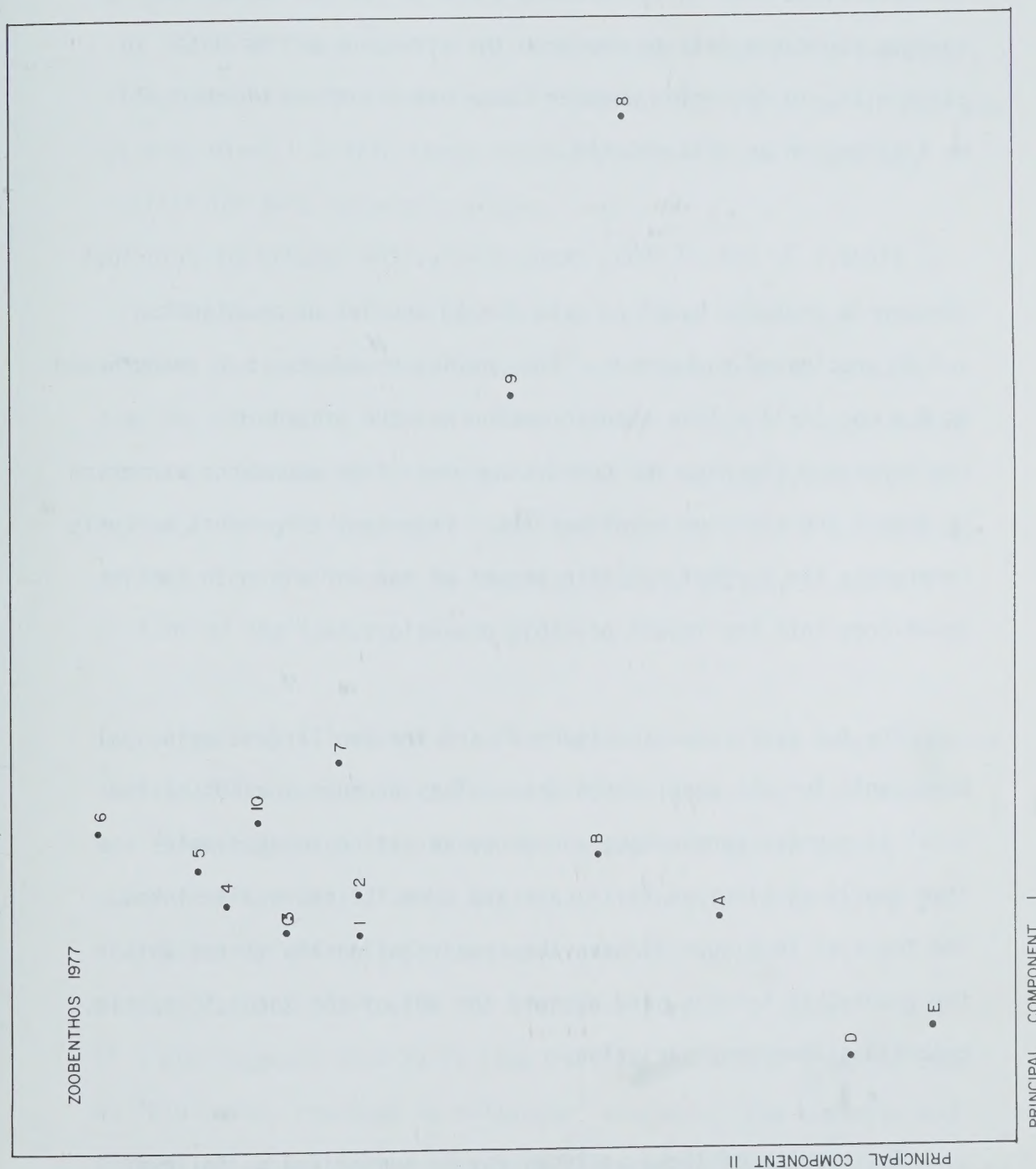


Figure 31. Principal components analysis based on the summer 1977 species abundance data for 50 species of zoobenthos.

Results and Discussion

The first step in the procedure was to use the summer 1977 species abundance data to evaluate the structure of the data, in particular, to determine whether there was any trend which could be interpreted as silt-related.

Figures 30 and 31 show, respectively, the results of principal components analysis based on data for 13 species of zooplankton and 50 species of zoobenthos. The species abundances are transformed as $Z = \text{Log}(X+1)$. This transformation has the effect of standardizing the data and converting percentage abundance variation to linear and additive relationships. Principal components analysis compresses the largest possible amount of the variation in species abundances into the fewest possible dimensions.

The two axes shown in Figure 30 are the two largest principal components for the zooplankton data. They account for 60% of the total 13 species zooplankton abundance variation among samples from the 10 stations in Ya-Ya Lake and from the other five lakes. The two axes in Figure 31 have the same relationship to the data for zoobenthic species, and account for 40% of the total 50 species zoobenthos abundance variation.

The results of these analyses may be summarized as follows:

1) Ya-Ya Lake is quite different from Lakes A, B, D, and E. Lake C, however, is similar to Station 3 in Ya-Ya Lake.

2) Stations 1 to 6 of Ya-Ya Lake show a trend with benthos. With zooplankton the same trend is present but the order of stations is more mixed. Within these trends, Stations 1 and 2 are very similar for both taxonomic groups.

3) Stations 7 to 10 are not part of the Station 1-6 trend. Station 10 is similar to Stations 1 and 2 only because certain species are missing from all three, though probably for different reasons. Station 10 is extreme in that it has the properties of a deep, clear, oligotrophic lake, and Stations 1 and 2 are extreme in that they are located in the most heavily silted, riverine portion of the lake.

Figure 2 illustrates the variation in turbidity among stations in Ya-Ya Lake during the summer of 1977. Values for Stations 1 and 2 are both high then there is a sharp drop and an uneven downward trend until, above Station 6, turbidity is uniformly low and evidently not an important environmental variable. This pattern is consistent with the biological trends (Figures 30 and 31) and suggests that Ya-Ya Lake Stations 1 through 6 can be used as "biological response to siltation" transect. The analyses and discussions which follow, for both 1977 and 1978 data, relate only to these stations.

The next step in the analysis was to identify those species whose abundance trends suggest a significant response to the gradient. Data for the summer of 1977 and the spring of 1978 were combined for this analysis.

Several possible measures of "species response to the Station 1-6 siltation gradient" were considered. Variance in species abundance ($\log [X+1]$ transformed) among stations was rejected as being too general a measure. That is, a high variance would not necessarily imply any relationship to the gradient--it could result from high abundances at, for example, Stations 2 and 6, and low abundances elsewhere. A rank correlation approach was also considered, but with only $N=6$ stations the power of the analysis would be very low. The measure chosen was the square root of the coefficient of determination (analogous to the correlation coefficient) in a regression of transformed species abundance on station number. In this regression, a high positive value implies an exponential increase in abundance from station to station up the lake (i.e., with decreasing turbidity), while a high negative value implies exponentially decreasing abundance with decreasing turbidity. Therefore, a significant high positive value identifies a "low turbidity indicator", and a significant high negative value identifies a "high turbidity indicator" (Table 36).

Of the four major taxonomic groups, the fish are most difficult to deal with in this analysis. They were sampled by a variety of

Table 36. Taxa predictive of turbidity gradient related to Ya-Ya Lake station 1 - 6.

Taxon	Root of coefficient of determination			
	Summer 1977	Summer 1978	Average	Indicator of
<i>Procladius</i> sp. (benthos)	-0.97 (p < .01)	-0.78 (p > .05)	-0.91 (p < .01)	turbid
<i>Diaptomus sicilis</i> (zooplankton)	+0.78 (p > .05)	+0.93 (p < .01)	+0.87 (p < .01)	clear
<i>Mysis relicta</i> (benthos)	+0.97 (p < .01)	+0.41 (p > .05)	+0.85 (p < .01)	clear
<i>Dinobryon borgei</i> (phytoplankton)	+0.92 (p < .01)	+0.44 (p > .05)	+0.77 (p < .01)	clear
(troutperch -fish)	-	-	-	(turbid)

methods (seine hauls, onshore gillnet sets, and offshore gillnet sets), and, within the area of the lake presently under discussion, only at Stations 1, 2, 3, and 6. Also, fish are highly mobile and tend to be aggregated (for example, in schools) so that impressively high abundance on one part of the gradient may represent some component of the life history (e.g., a spawning run) rather than any long-term response to turbidity. As an example, during the summer of 1977, Arctic cisco were caught in seine hauls at Stations 3 and 6 but not at Stations 1 and 2. In gillnets they were caught at Stations 1, 2, and 3, but not at 6. In the spring of 1978, they were caught at all stations by every method. The only species for which there is a suggestion of a consistent pattern over the two years is the trout-perch as sampled by seine hauls. In both 1977 and 1978, it was present in fair abundance at the lower, more turbid stations but absent at Station 6. It is included in parentheses in Table 36 to indicate that it is a possible indicator species but difficult to evaluate.

At the bottom of Figure 32 is shown the taxonomic composition of the communities in both summers. In the summer of 1977, 74 taxa were included in samples from one or more of the Stations 1 through 6. Of these taxa, six were zooplankton, 25 benthos, 29 phytoplankton, and 14 fish (by seine hauls). In the spring of 1978, there were again 74 taxa in samples from Stations 1 through 6, three of which were zooplankton, 25 benthos, 39 phytoplankton, and 7 fish by seine hauls. As might have been expected, the benthic

community appears to be most stable and the phytoplankton most variable between years.

In 1977, of 41 taxa which were present at two or more of the six stations, five showed a relationship with the Stations 1-6 turbidity gradient which was significant at the 0.05 level, and three showed a relationship which was significant at the 0.01 level. This may be contrasted with the $41/20 = 2$ taxa, and $41/100 = <1$ taxa, respectively, that would have been expected by chance alone. The same pattern was repeated in 1978. Of the 41 taxa which were present at two or more of the six stations, 12 showed a relationship with the Station 1-6 turbidity gradient which was significant at the 0.05 level, and 7 showed a relationship which was significant at the 0.01 level. The numbers of taxa that would have been expected by chance alone were the same as for 1977: $41/20 = 2$ taxa, and $41/100 = <1$ taxa, respectively.

These results, and the biological patterns in Figures 30 and 31 related to the turbidity gradient shown in Figure 2, suggest that there are taxa whose distributions are related to the turbidity gradient. However, a conservative stance was taken in identifying such taxa, requiring that the relationship with the turbidity gradient have a probability of less than 0.01 by chance alone, both for the average in the two years taken together and for the relationship in at least one of the two years considered separately. Four taxa satisfied these criteria (Table 36). Their

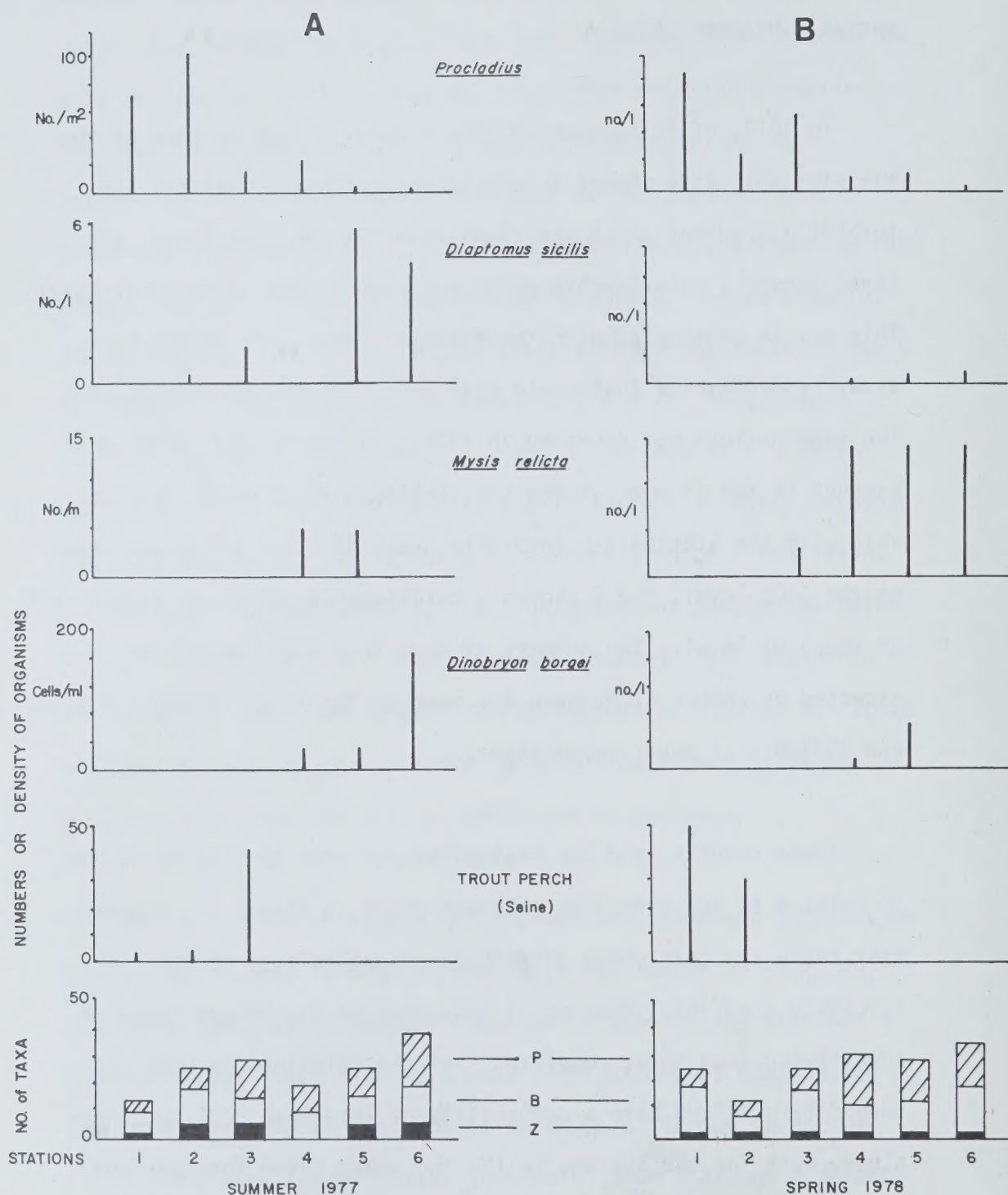


Figure 32. Abundance of five organisms along the turbidity gradient in Ya-Ya Lake in summer 1977 and spring 1978. Also shown is the taxonomic composition of the communities in both open-water sampling periods (P is phytoplankton, B is zoobenthos, Z is zooplankton).

abundances along the gradient are shown for the two years, in Figure 32.

Two of these "predictor taxa" are included among the zoobenthos, although one of them, *Mysis relicta*, is commonly planktonic. It is included with the benthos here because it was collected in the benthic sampling by Ekman grab. There is one representative each of the zooplankton and the phytoplankton which are probably best considered to be rapid response, short-term indicators of turbidity. These results strongly suggest that it is dangerous to choose criteria for biological monitoring, including selection of indicator species, based on data for a single year or a single season. One example will suffice. During the summer of 1977, *Cryptochironomus* sp. B showed a highly significant positive relationship with the turbidity gradient ("indicator" of clear conditions), whereas in the spring of 1978 it showed a significant negative relationship with the gradient ("indicator" of turbid conditions).

DISCUSSION AND CONCLUSIONS

DISCUSSION AND CONCLUSIONS

THE YA-YA LAKE STUDY AND THE PROBLEM
OF QUANTITATIVE STANDARDS FOR SUSPENDED SOLIDS

Introduction

Probably the best approach to controlling sedimentation in natural waters in the north is an insistence on proper design, incorporating such features as buffer strips, erosion control devices, settling basins, used in conjunction with such environmentally determined variables as location (e.g., away from spawning, rearing, and overwintering areas) and timing (during periods when sediment loads are naturally high). There is a body of opinion, however, represented by Berger (1977), which feels that this kind of site-specific approach is impractical in relation to major developments such as pipelines and that, "the principle of numerical standards should, therefore, be vigorously promoted" and that these will "... provide the cornerstone of a sound fish protection program." Berger sees the standards variously as:

1) a guide for those concerned with the design, review, operation of development projects;

2) criteria that must be met by design engineers;

3) operating specifications that must be followed by operational personnel;

4) standards that can be enforced.

Berger suggests that the standards to be used in these ways should be quantitative, objective, enforceable, practical (e.g., routinely workable by small staff not highly skilled in scientific sediment load assessment practices), and indicative of both short- and long-term increases in sediment loads. Obviously Berger intends such standards to bear a very heavy burden in the regulation of developments.

One of the purposes of this study was to examine the question of suspended sediment standards in light of the information generated during the Ya-Ya Lake study. In this section we present a general consideration of the Ya-Ya Lake study, an examination of Berger's proposed standards, and some recommendations regarding other approaches to the development of standards.

The Ya-Ya Lake Studies

The European Inland Fisheries Advisory Commission (EIFAC) Working Party on Water Quality Criteria for European Freshwater Fish (1964) reviewed the effects of chemically inert suspended solids on mortality, growth, resistance to disease, reproduction,

behaviour, and food supply of fishes. They concluded (summarized by Sherk and Cronin, 1970) that not all species of fish are equally susceptible to suspended solids and not all kinds of solids are equally harmful. There is probably no single solids concentration level above which fisheries are damaged and below which they are unharmed. However, any increase in the normal prevailing suspended matter concentration may cause a decline in value and status of a fishery, and the risk of damage increases with concentration. The relationship is not clear but tentative criteria with respect to chemically inert solids in otherwise satisfactory fresh waters are as follows:

- 1) There is no evidence that concentrations of inert suspended solids less than 25 mg/L have any harmful effects.

- 2) Although the yield of fish may be somewhat lower in waters normally containing 25 to 80 mg/L suspended solids, it should be possible to maintain good to moderate fisheries.

- 3) It is unlikely that waters containing 80 to 400 mg/L suspended solids will support good fisheries.

- 4) At best only poor fisheries are likely to be found in waters which normally contain more than 400 mg/L suspended solids.

These criteria refer to normal or average conditions over a long period of time rather than to short-term peaks such as may

occur during natural events such as freshets or even those which may occur as the result of human activity.

While the criteria are stated in terms of the effects on fisheries, the fish species themselves may not be directly affected by sediments, especially at the lower concentrations. Reductions in the productivity of fisheries may, rather, be a reflection of adverse effects at much lower trophic levels within aquatic ecosystems. If, for example, primary production is drastically reduced as the result of an inhibition of photosynthetic activity resulting from high turbidity, fish production will ultimately be reduced as well.

Table 37 relates the EIFAC suspended solids criteria to data describing the standing crops of various groups of aquatic organisms in Ya-Ya Lake. No concentrations in excess of 400 mg/L were recorded at any of the stations. Among the phytoplankton, zooplankton, and zoobenthos, there was, as expected, a general increase in standing crops with increasing water clarity. With fish, however, this tendency was reversed. Because of their high mobility and the ready access of both anadromous and stream resident fish to Ya-Ya Lake, fish numbers do not necessarily reflect the productivity of the lake itself.

The differences in standing crops indicated in Table 37 are not, of course, solely a reflection of differences in suspended

Table 37. Relationship of EIFAC suspended solids criteria to mean values for the standing crops of various major groups of aquatic organisms in Ya-Ya Lake, summer, 1977 and spring 1978 data combined.

Stations	Susp. Sed. (mg/L)	Phytoplankton Biomass (mg/m ³)	Zooplankton Abundance (No/L)	Zoobenthos Density (No/m ²)	Fish Catch (No)
1 - 2	80 - 400	69.7	2.50	1080.0	148.5
3	25 - 80	349.0	14.38	1149.0	144.0
4 - 10	0 - 25	454.5	27.10	1240.5	61.0

solids concentrations. During much of the open water season, and particularly during the spring freshet, the lake can be considered as consisting of two distinct bodies of water with a variable zone of interface between them. There is a body of standing water, consisting of Region III and a variable portion of Region II, which is truly lacustrine, affected only by wind generated currents, and characterized by clear waters. There is a second body of water, Region I and parts of Region II, which during the open water season is part of the Mackenzie River, influenced by gravity currents and characterized by turbid waters. Thus, during this most productive season, the characteristics of populations of aquatic organisms near the outlet end of the lake may be more reflective of conditions in the Mackenzie River than of a modification of a purely lacustrine environment due to the effects of sedimentation. Rather than a relatively homogeneous environment in which there is significant variation in only a single major variable, suspended solids concentration, we have a complex multibasin lake in which there are biologically significant differences between areas and among seasons in water depth, substrates, water quality, current velocities. We are unable, therefore, to draw any but the most general conclusions, both within groups or overall, about the impact of sedimentation on communities of aquatic organisms within Ya-Ya Lake. While sediment loading seems to have had an adverse effect on both primary and secondary production, these effects cannot be quantified in terms of, for example, the per cent reduction in production to be expected at various levels of sediment

concentrations. Attempts to use multivariate analytical techniques in assessing the relationship of suspended solids concentrations to populations of species and groups have been largely frustrated by the high variability in the data (Section on Multivariate Analysis). More than anything else, the study has illustrated the difficulty of measuring and assessing the impact of sedimentation in natural situations.

The Berger Standards

While we are not able, on the basis of the results of this study, to develop any quantitative relationship between suspended sediment concentrations and the degree of impact which might occur in lacustrine ecosystems in the north, there has, as previously indicated, been one attempt (Berger, 1977) to define acceptable quantitative standards for suspended sediment concentrations in both lakes and streams in the north. There is a possibility that this or other similar set of standards will be applied in controlling and monitoring major developments in northern Canada and, for this reason, Berger's approach to the problem deserves careful scrutiny.

Outline of Proposed Method

Berger's argument is presented, in part, in Volume 2, Terms and Conditions, of the Mackenzie Valley Pipeline Inquiry and, in part, in supporting documentation (Commission Counsel, 1976, "Fish

Protection: Suspended Sediment Standards"). Briefly, it is as follows:

1) Development in the north is likely to result in greatly increased suspended solids concentrations in both lakes and streams.

2) Suspended solids may damage populations of fish by settling out on substrates, reducing populations of fish food organisms or damaging spawning beds.

3) Standards must be established which provide a practical means of measuring silt loads and which provide criteria for adequately protecting populations of aquatic organisms.

4) The parameter best documented with respect to its effects on the productivity of fish populations is suspended solids (non-filterable residue). Suspended solids concentrations are not, however, easily measured in the field and turbidity, a correlated parameter, more easily determined by unskilled personnel in the field, is recommended instead.

5) The relationship of turbidity to suspended solids concentration for the Mackenzie River Drainage can be determined from data stored in the NAQUADAT system (Environment Canada). This relationship can then be used to convert recently recommended suspended solids criteria (U.S. National Academy of Sciences and National Academy

of Engineering, 1974) to nephelometric turbidity units (NTU) as follows:

<u>Level of Protection</u>	<u>U.S. Criteria Maximum SS, mg/L</u>	<u>Corresponding Mackenzie Maximum Turbidity, NTU</u>
High	25	18
Moderate	80	45
Low	400	157
Very Low	Over 400	Over 157

6) In lakes or ponds, samples shall be taken at the approximate distances from the source of sediment given in the following table. The direction of the sampling site from the construction shall be that of maximum effect, depending upon currents and wind. A control or "natural" sample shall be taken in a very similar nearby waterbody, or in an unaffected part of the same one, if that is possible.

<u>Greatest Dimension of Lake or Pond</u>	<u>Distance of Sampling Point</u>
Less than 400 yards	One half of the longest dimension
400 yards - 1 mile	200 yards
1 mile - 10 miles	300 yards
More than 100 miles	350 yards - 0.2 miles

7) At the specified distance from operations, turbidity of the water shall not average more than 27 times the natural level during any 8 hour period, nor more than 9 times the natural level during any 96 hour period, nor more than 3 times the natural level during any 30 day period.

8) An "Invertebrate Standard" may be used in conjunction with the "Turbidity Standard" described above. At the specified distance from operations, the Shannon Diversity Index for bottom-living aquatic macroinvertebrates shall not be changed more than 25% from the control value as a result of the addition of finely-divided solids.

Benthic macroinvertebrates may be taken with any quantitative device proven to be reliable. The device should sample at least 0.1 sq m or 1 sq ft. The same apparatus shall be used to sample "natural" and "affected" areas. Sampling shall be carried out at the same time in both places, since communities may vary seasonally.

It is of utmost importance that the two biological sampling places have nearly identical habitat. For this reason, it is permissible to adjust the "affected" sampling location to get a section of habitat that is both suitably similar to the "natural" section and close to the stipulated point.

One good sample is generally sufficient for routine purposes. In cases of irregularities or suspected damage, two or three samples are usually adequate to establish variability at a given location.

There are a number of problems with the Berger approach. First, and most serious, is the substitution of turbidity measurements for determination of suspended solids concentrations.

The Turbidity-Suspended Solids Relationship

Most aquatic biologists would agree that in stream environments the most serious consequences, in the short-term, of increased sediment production are the effects of settleable solids. These are the materials which are heavy enough to settle out and, where sufficient quantities are present, blanket lake and stream substrates, smothering benthic invertebrates and fish eggs. Settleable solids, however, are not often measured during the course of studies in natural waters. More often, measurements are made of suspended solids (non-filterable residue). Suspended solid measurements can be used as an index of settlement presuming that where suspended sediment concentrations are high, settleable solids levels will also be high. For example, a source of sediments which produced a high concentration of suspended sediments at a sampling point some distance away might be supposed to be potentially more damaging than one which produced a lower concentration at an equivalent distance. In fact, quite the reverse might be true. The lower concentration might indicate only that a high proportion of the solids produced had settled out between the source and the sampling point either because of the nature of the substrate (e.g., having a high proportion of large, readily settleable materials) or the lower carrying capacity of the receiving waters (e.g., in streams or in lakes where there are wind generated currents, low velocity waters can carry relatively less material than those of higher velocity) or both.

Obviously, there are difficulties in using suspended sediment concentrations as an index of settleable solids and of the likelihood of damage to aquatic habitats. Nevertheless, Berger and his Commission Counsel propose to go beyond even this and to use turbidity rather than suspended sediment concentrations as a standard for development activity. Their argument is that suspended sediment concentrations are difficult to measure in the field while turbidity, a related parameter, can be readily determined. In our view, the relationship of turbidity to suspended sediment concentrations (and, more importantly, to settleable solid levels) is not sufficiently precise to permit an easy conversion of one to another and that any sediment standard based on an assessment of turbidity values is unacceptable.

There are a number of reasons for this conclusion:

- 1) The turbidity values which Berger suggests as maxima for various classes of streams are based on data for a number of streams within the Mackenzie Drainage (from the National Water Quality Data Bank--NAQUADAT) yet the scientific literature indicates that there is no basis for the derivation of turbidity/suspended solids curves from data for groups of streams. Duchrow and Everhart (1971), who examined the question in some detail, found that "Turbidity may be a useful parameter as an index to suspended sediment source in individual water systems if the sediment source remains constant." However, "Each stream must be calibrated and the resulting curve

could only be applied to that stream ... Care should be exercised in using these relationships not to extrapolate beyond the limits of existing data. A single curve cannot be set up to apply to all streams because the type of sediment received by each system is potentially different..."

2) Even if one chooses to ignore Duchrow and Everhart, it seems reasonable that the streams included in the baseline group should be comparable to those likely to be affected by development and for whose protection, criteria are being developed. Berger's intention was to develop standards to be applied during the construction of a gas pipeline up the Mackenzie Valley and possibly across the North Slope of the Yukon Territory. We have examined the data base for Berger's argument and find that, of the 33 streams on which his assessment is based, only seven (Trout, Willowlake, Blackwater, Saline, Great Bear, and Hare Indian River, and the Mackenzie River itself) lie along the pipeline route that had been proposed. Five (the Anderson, Coppermine, and Tree rivers and Ellice and Southern creeks) lie entirely outside the Mackenzie River Drainage and far to the east of the pipeline route. Several are large, relatively turbid tributaries of the Mackenzie River (e.g., the Liard, North Nahanni, Keele, Redstone, Mountain, Ramparts, Arctic Red, and Peel rivers), of a kind not found anywhere along the route that had been proposed. None of the streams is representative of the small, high quality tributaries of the Mackenzie River which drain the Norman and McConnell ranges and

which appear to be most sensitive to the effects of sedimentation. These streams (Oscar, Prohibition, Vermilion, and Hodgson creeks are examples) are typified by clear waters and clean substrates and are important spawning and rearing habitats for grayling. None of the streams included in Berger's assessment lies along the segment of the proposed pipeline route which would have crossed the Yukon North Slope, an important omission in view of the fact that, in the absence of any statement to the contrary, the proposed standards would presumably have applied to all pipeline construction in Canada north of 60°.

It is also important, in view of the fact that Berger wishes to apply his standard to lakes as well as streams, that none of the NAQUADAT data included in his baseline group describe the turbidity-suspended solids relationship for lakes.

3) As might be expected, in view of the wide range of stream types included in the sample, the relationship of turbidity to suspended sediment concentrations indicated by the NAQUADAT data is a very poor one (Figure 33). An examination of this figure indicates the following:

a) The line indicated on the figure, the one apparently used in calculating maximum turbidities for various levels of protection in the Mackenzie system, was apparently fitted by eye and was not machine calculated. The latter would have provided

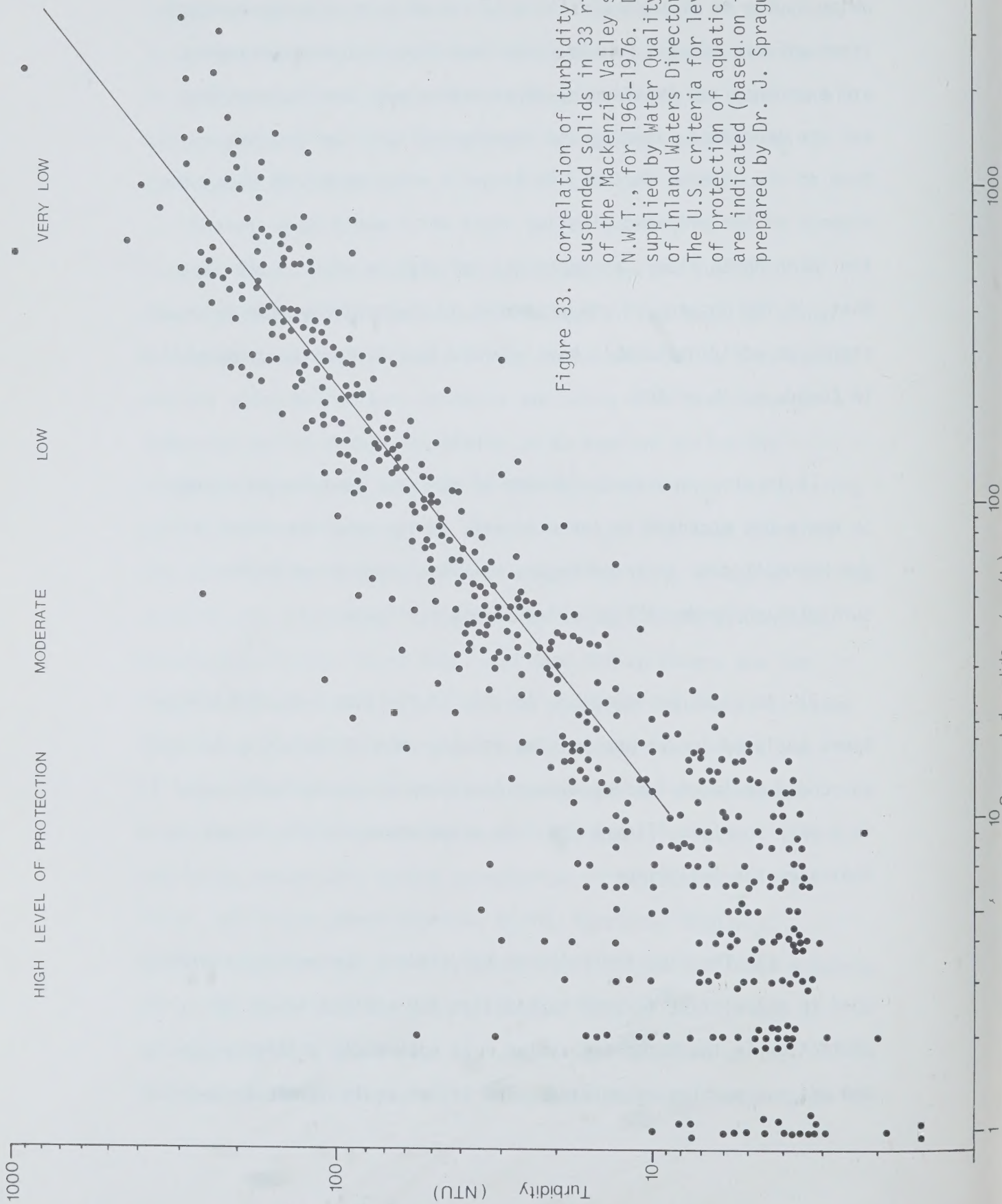


Figure 33.

Correlation of turbidity with suspended solids in 33 rivers of the Mackenzie Valley system, N.W.T., for 1965-1976. Data supplied by Water Quality Branch of Inland Waters Directorate. The U.S. criteria for levels of protection of aquatic life are indicated (based on figure prepared by Dr. J. Sprague).

a more objective basis for determination of maximum levels.

b) The linear relationship indicated by the line breaks down at suspended sediment values between 10 and 20 mg/L and does not apply to values lower than this where the distribution of points suggests that there may be no significant correlation between the two parameters. Unfortunately, this lower range includes many of the more productive waters in the Mackenzie Valley such as clear lakes and small spring-fed drainages. It also includes winter values for many bodies of water which are generally turbid during the open water season. Even in the Mackenzie River, for example, which is extremely turbid during the open water season, values of less than 5 NTU suspended sediment have been recorded in late winter (Mann, 1975).

There are several factors which may contribute to poor correlation at low values of the two parameters. One is that readings with turbidity meters tend to be more variable at low values (Duchrow and Everhart, 1971). The second is that at low values, turbidity resulting from factors other than suspended solids, particularly humic acids and other stains, becomes proportionately more important, a potential problem in many small lakes and streams in the Mackenzie Delta.

c) The variability in the data presented in Figure 33 is less apparent than it might be because the data are presented in

log/log form. The practical problem of using data with such a high degree of inherent variability is best illustrated with a few examples in which, as Berger apparently intends, turbidity values are used to estimate concentrations of suspended solids. For example:

i) for turbidity values between 60 and 65 NTU, in the low range of values, the corresponding suspended solids concentrations range from less than 1 to 24 mg/L, a difference of more than 24 times between the high and low values;

ii) for turbidity values of 30 to 35 NTU (middle range) the corresponding suspended solids values range from 2 to 270 mg/L, a difference of 135 times;

iii) for turbidity values between 250 and 260 NTU (high range), the corresponding suspended solids values range from 50 to 2200 mg/L, a difference of 44 times.

With respect to developmental activities, there is another potential source of variation in the turbidity-suspended solids relationship which must be considered. That is, that the materials which enter waterbodies from such sources may differ in their characteristics from natural sources and have very different turbidity-suspended solids relationships. Examples might be mine tailings or drainage from long-buried materials deposits. Mine tailings especially, may be finely divided and have turbidities which are very high in relation to their suspended solids

concentrations. Thus, even if a relatively precise turbidity-suspended solids relationship is developed for an individual body of water, it may not be appropriate in assessing the impact of sedimentation resulting from development.

Regarding the development of turbidity-suspended solids relationship for individual bodies of water, it is worth noting that the results of this study indicate that there may be significant seasonal and spatial differences in the relationship even within individual lakes. In the summer of 1977, the relationship between the two parameters was significantly different, in both slopes and intercepts, from what it was in the spring of 1978 (Figure 3). Also, in both sample periods, the ratio of settled to shaken turbidity varied from station to station within the lake (Figure 4).

The Macroinvertebrate Standard

Berger, on the advice of Commission Counsel, recommends that a Macroinvertebrate Standard, based on the Shannon Diversity Index, be used in conjunction with the Turbidity Standard to provide an assessment of the biological effects of an increase in sediment. This standard is intended primarily for assessing the continuing or long term effects of development. Berger further recommends that, "In questionable cases, findings of the biological survey should take precedence over the physical and chemical surveys." He obviously intends to attach a great deal of weight to this biological

standard and notes that it is sensitive, reliable, and conducive to use by both professionals and laymen alike. There are, however, some difficulties in the use of diversity indices to assess the impact of suspended solids on lake ecosystems.

In the first place, although the Shannon and other similar diversity indices are quite sensitive to the effects of various types of organic pollution (Wilhm, 1970), they appear to be less so to the effects of inert, non-toxic pollutants such as suspended solids. If only moderate amounts of the latter are introduced into aquatic systems, there may be significant changes in the density of benthic macroinvertebrates but little reduction, or even increases, in species diversity (Gammon, 1970; Rosenburg and Snow, 1975). Such situations can occur, for example, where the original fauna is dominated by a few species, especially sensitive to sedimentation, which are reduced in numbers while most of the community, less sensitive to moderate levels of sedimentation, survive at their former levels. In this situation, the resulting community is more "even" and the value of the Diversity Index increases despite the fact that overall density may have seriously declined due to the loss of a few dominant species. We have, ourselves, observed increases in both Shannon-Weaver Diversity Indices and Equitability downstream of pipeline crossings, which could be ascribed to the disproportionate loss of a few dominant species and rare taxa, despite the fact that the overall density of benthic macroinvertebrates had been reduced by approximately

50% (AEL File Report to Canadian Arctic Gas Study Limited, 1976).

While the Shannon Diversity Index may not be sensitive to moderate levels of sedimentation, at high levels few, if any, benthos survive and both densities and species diversity are markedly reduced.

In summary, it would appear that the Shannon Diversity Index, and probably diversity indices in general, are not specially sensitive to the kind of pollutant, suspended sediments, for which Berger intends it to be used and is probably better suited to the assessment of the effects of organic and toxic pollutants (e.g., in the north, domestic sewage, oil and fuel spills, methanol, lubricants).

There are, briefly, several other problems with Berger's approach to the use of the Shannon Diversity Index as a Macro-invertebrate Standard.

1) Commission Counsel indicates that for routine purposes, one good sample, obtained with a standard sampling apparatus such as a Surber sampler, should be generally sufficient. AEL has examined the question of the number of samples required to obtain a reasonable estimate of the value of the Shannon-Weaver Diversity Index (McCart et al., 1975). In the stream (Sheep Creek, near Grande Cache, Alberta) in which the study was conducted, single samples gave values which averaged 29% less than those calculated

for two or more samples. It was concluded that at least two samples were required to give a reliable index of diversity. Thus, the sampling error associated with estimates based on single samples will, itself, frequently exceed the 25% difference which Berger suggests is indicative of adverse environmental effects.

2) This 25% difference is, as Commission Counsel admits, "arbitrary" and may need revision in view of the apparent insensitivity of the parameter to suspended solids concentrations. It is quite conceivable, as suggested above, that there might be serious adverse effects to benthic communities with any change in its diversity indices.

Finally, with regard to the point that the Shannon Diversity Index is "conducive to use by both professionals and laymen alike", like any other biological phenomenon, community diversity is the result of a complex of interactions and any simplistic interpretation of environmental changes based on this single parameter can lead to dangerously erroneous conclusions. Warren (1971) has warned that,

"...a diversity index is only a manifestation; alone it provides no framework for causal explanation. It is a useful and powerful tool for describing certain community phenomena; the explanation of these phenomena requires other knowledge. It can be a very useful biological

index of community or environmental change. It should not replace the use of other knowledge about the biology and environmental requirements of the species contributing to diversity. Tables of species and numbers, as subjective as their analysis may be, still permit use of knowledge about individual species in their interpretation. There is no single path to understanding."

Sampling Locations

The rationale for determining the distance of sampling points from sources of disturbance in lakes and ponds is not given in either Volume II of the Berger Report or in the Commission Counsel's recommendations. The relationship is neither arithmetic nor exponential and the logic remains obscure. The sample distances take no account of current speeds and differences in dispersion between wind-exposed and protected lakes. The Counsel recommends that the sample should be taken in the direction of maximum effect depending on current and wind with no comment on procedures to be followed under ice cover when the direction of maximum effect is not readily apparent. There is no suggestion concerning the depths at which the sample should be taken. This can be an important consideration in standing waters which have a more pronounced three dimensional structure than streams and where density currents and layering are more common.

There is, however, a much more basic problem with Berger's

recommendations regarding sampling locations than those outlined above. That is his recommendation that if a control sample cannot be taken in an unaffected part of the same waterbody, it should be taken in a similar, nearby waterbody. In examining the results of this and other studies (McCart et al., 1976; Machniak, 1977) of lakes in the Mackenzie Delta and adjacent areas, one is more impressed by the variability among lakes than by their similarities. Even within individual lakes (e.g., Ya-Ya Lake and Lake C) there may be great differences between areas. The differences may be even greater between lakes, particularly with respect to the benthic macroinvertebrate standard (Discussion in the section on Zoobenthos). The characteristics of macrobenthic communities are influenced by a multiplicity of factors and a superficial resemblance between waterbodies in water quality, morphometry, and substrate type do not in themselves guarantee a similarity in species diversities as indicated by the Shannon Diversity Index.

The selection of control sites which are to be located in a body of water other than the affected one is not a trivial matter and should only be done after intensive investigation of various alternatives.

Recommendations

In view of the complexity of the problem, we are unable to make any recommendations regarding quantitative criteria which can be used in regulating sedimentation resulting from development projects in the north. We can, however, present some general recommendations regarding the kinds of approaches which should be examined.

1) As a basis for developing more precise criteria in future we recommend that detailed monitoring studies be carried out in the vicinity of development projects in the north which are likely to result in heavy sedimentation to determine what, in fact, the short- and long-term effects are.

2) That increased attention be given to the definition of improved design standards for the regulation of developments likely to affect natural waters. These, which are applied before construction begins, are likely to give better control of sedimentation than the application of standards such as Berger's which only indicate conditions after environmental damage may have already occurred.

3) Because the most serious consequences of increased sediment loads are likely to be short-term effects resulting from the blanketing of substrates, we would recommend that any quantitative

standard that is developed be based on a more direct measure of settleable solids than is turbidity. Field measurements of suspended and settleable solids do not appear to us to be nearly as difficult as Berger suggests.

4) Because biological communities take some time to respond, especially to the more subtle effects of environmental degradation, biologically-based standards such as Berger's Invertebrate Standard are not very useful in assessing anything but the long-term effects of sedimentation. They are not, therefore, appropriate in regulating the day-to-day operations of a development project. In assessing long-term effects, biologically-based criteria are, however, probably preferable to any physical parameter. We would recommend further studies of the effects of suspended sediments on aquatic organisms using a controlled, experimental approach which eliminates much of the uncertainty in interpretation associated with studies of natural systems such as Ya-Ya Lake.

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